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THE TEMPERATURE/HUMIDITY RECORDING SYSTEM - A USER'S GUIDE

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Natick, Massachusetts

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13. ABSTRACT

This document is an instructive guide describing a small lightweight battery-operated tape recording system for gathering data on shipping and storage temperature and humidity conditions within containers.

A specialized magnetic tape recorder is used with resistive temperature and humidity sensors to generate hourly outputs that are magnetically stored in two tracks of 1/4-inch (6.35-mm) recording tape by means of a four-channel recording head. A third track is used for recording time reference marks, and the fourth track is available for recording other information.

A separate playback deck with means of monitoring the playback signal is used for retrieval of data. Peak amplitudes of playback pulses are proportional to the recorded temperature and humidity values.

The system is prepared for shipment by electrically coupling a power source and the sensors to the recorder and then packing the complete system within a shipping carton of dimensions sufficient to allow adequate cushioning of the recorder. A thorough checkout of recorder functions should be conducted before shipment to insure reliable readings. Response to known inputs should be included in the checkout. A calibration schedule of known temperature and humidity conditions preceding and following system shipment is recommended to provide a "same reel" reference for in-transit recordings.

Many recorder malfunctions may be corrected by the user with troubleshooting and repair procedures outlined herein. Recording range and slope can be easily adjusted by the user.

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	ROLE	WT	ROLE	WT	ROLE	WT
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Temperature	9, 4		9			
Humidity	9, 4		9			
Measurement	4		8			
Tape recorders	10		10			
Materials handling	4		4			
Data			8			

FOREWORD

The original investigation that resulted in the Temperature/Humidity Static Load (T/H/(L)) recording system were conducted under Contract DA19-129-QM-2082 (OI 6150) by the Shock and Vibration Division of Mitron Research and Development Corporation with Mr. Maurice Gertel as Principal Investigator and Mr. David Franklin as Project Engineer.

Project Officer and Alternate Project Officer for the U. S. Army Natick Laboratories were Mr. Matthew A. Venetos and Mr. Denis J. O'Sullivan, both formerly of the Engineering Sciences Division of the General Equipment and Packaging Laboratory.

This contract was originally funded under Project 7X91-03-015 and later transferred to Project 1M643324D587.

Static compressive load measuring concepts were developed by the Anatole J. Sipin Company under Contract DAAG17-67-C-0168, with Anatole J. Sipin as Principal Investigator.

Subsequent investigations funded under Project 1J662708D552 were conducted by the Engineering Sciences Division, General Equipment and Packaging Laboratory, to develop the described T/H/(L) recording system configuration.

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THE TEMPERATURE/HUMIDITY RECORDING SYSTEM
A USER'S GUIDE

1. General Information

a. Introduction

This manual describes an environmental recording system for instrumenting shipping containers. The recording device is a 1/4-inch (6.35 mm), four-channel magnetic tape unit similar to that described in "The Drop Height Recording System - A User's Guide", TR 72-72-GP. Temperature and humidity sensors, a battery pack, and the necessary packing material complete the system. On two of the channels hourly readings of both the temperature and the humidity inside the package, over the ranges -40°C to 65°C and 10% RH to 95% RH, can be taken for periods up to six months. Timing marks are recorded once each hour on another channel to provide a time reference and an additional channel is available for the hourly recording of other data such as the static compressive load on a package (see section 5). The recorder's tape contains an environmental history of the package upon completion of a shipment.

This recording system was developed to obtain reliable information on conditions within military shipping containers during shipment and storage. Temperature and humidity records for various routes and modes of transportation and under many storage conditions can be taken. Estimates of maximum, minimum, and average temperatures and humidities can be made. Determinations of protection required or the risk involved can be found.

This guide was written to provide users of this system with the information necessary to most efficiently utilize the data gathering capabilities of this instrumentation. Step by step procedures for preparation, checkout, and calibration are included. Readout techniques and system optimization are also described. A detailed theory of operation, schematics of all electronic circuits, and troubleshooting procedures enable the user to correct system malfunctions. This guide can educate those unfamiliar with the system and can serve as a reference to those more experienced.

b. Specifications:

Dimensions	Size in cm (inches)	Weight in kg (lb)
Recorder Only:	19 x 16.5 x 11.7 (7 1/2 x 6 1/2 x 4 5/8)	3.15 (7)
Battery Pack:	19 x 13 x 7 (7 1/2 x 5 1/8 x 2 3/4)	2.70 (6)
System:	23.7 x 30.6 x 41.2 (9 3/8 x 12 1/4 x 16 1/4)	8.10 (18)

Recording Medium: 1/4-inch (6.35-mm) magnetic instrumentation tape, 1.0 to 1.5 mil, Ampex 738 or 748

Tape Capacity: 30 m (100 ft), 1.0 mil;
21 m (70 ft), 1.5 mil
(maximum of two years supply)

Mode of Recording: Stationary, no bias, 1.6 mm (1/16 inch) step after recording

Recording Head: Nortronics 5675

Recording Channels: Four: Temperature, humidity, time, and spare (static load)

Maximum Unattended Operation (battery life limitation): Six months

	Temperature	Humidity
Measurement Ranges:	-40°C to 65°C	10% RH to 95% RH
Accuracy:	± 3°C	± 10% RH

Fragility: 250 g

Power Requirements: +45V, +15V, +1.32V

Sensor Connector: Amphenol 126-218

Power Connector: Amphenol 126-198

c. <u>System Components</u>:

(1) <u>Recorder</u>. The T/H/(L) recording unit (Figure 1) is a special battery operated magnetic tape deck upon which is mounted co-axial supply and take-up reels, the recording head, stepping motor, batteries, timer, and potted electronic assemblies for controlling, stepping and recording. (See Appendix D, Figure D1.) This assembly is inclosed in a protective aluminum box.

The timer is an Accutron device which has a contact closure once each hour. (An additional set of contacts is available for a 6-hour option.) Contact closure triggers time pulse recording, tape advancement, and a 45-second time delay. Tape advancement is accomplished by pulsing a Ledex No. 216020-020 rotary stepping motor to move the tape reels. At the conclusion of the time delay a univibrator is triggered causing recording on motionless magnetic tape.

(2) <u>Sensors</u>. The temperature sensor (Figure 2) is a network consisting of two parallel thermistor-resistor combinations in series. The thermistors are Yellow Spring Instruments #44001 (100 ohm) and #44005 (3,000 ohm) and the resistive elements are 1,000 ohms each. The thermistive elements are encapsulated in Stycast resin for protection. The time constant for these elements in free air is 10 seconds and the dissipation factor is 1 mw/^{o}C. This sensor is used as one arm of a Wheatstone bridge across which is impressed at record time a regulated voltage pulse. The output of the bridge is fed to the recording head.

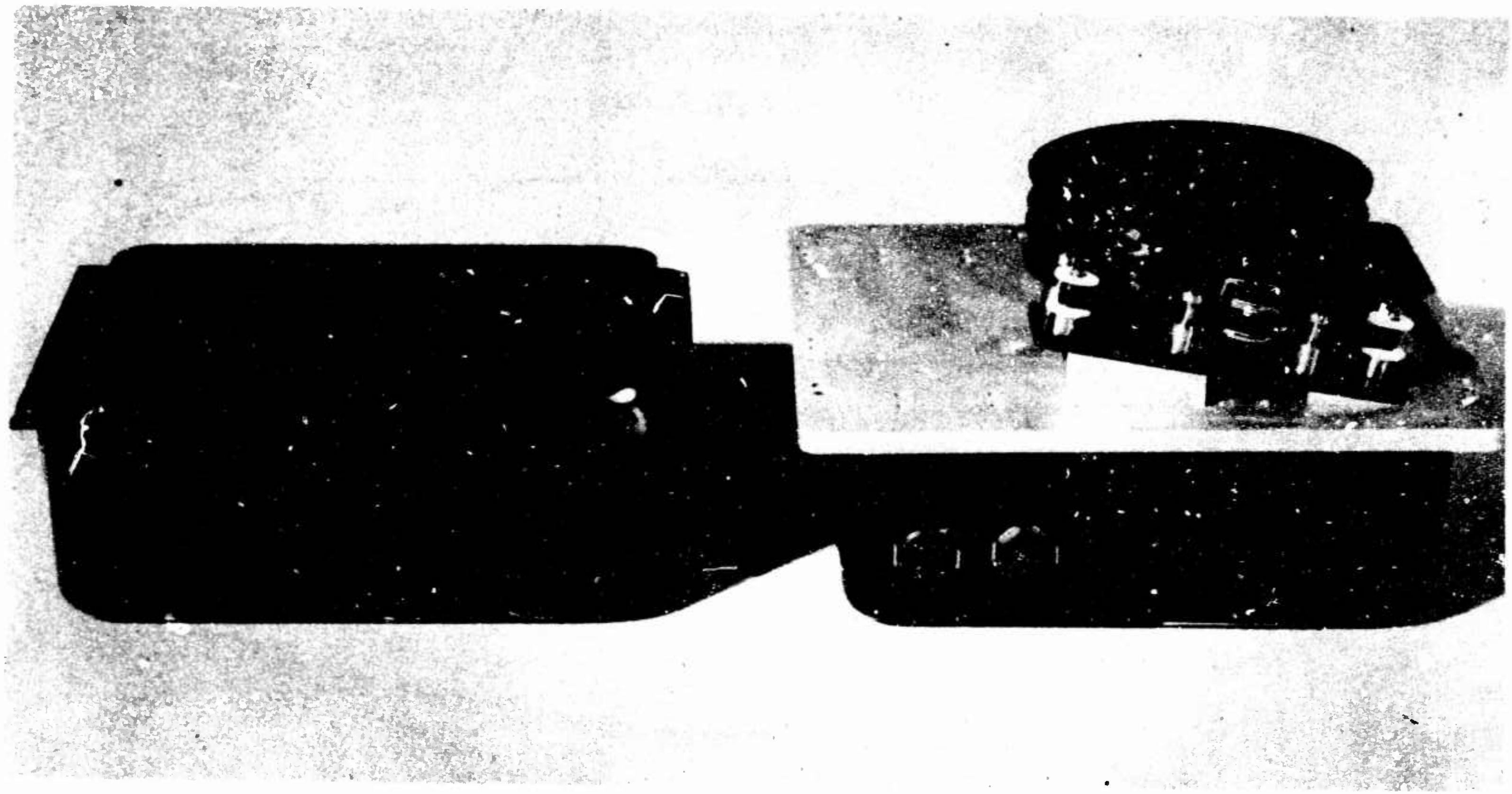

Figure 1. Recording Unit.

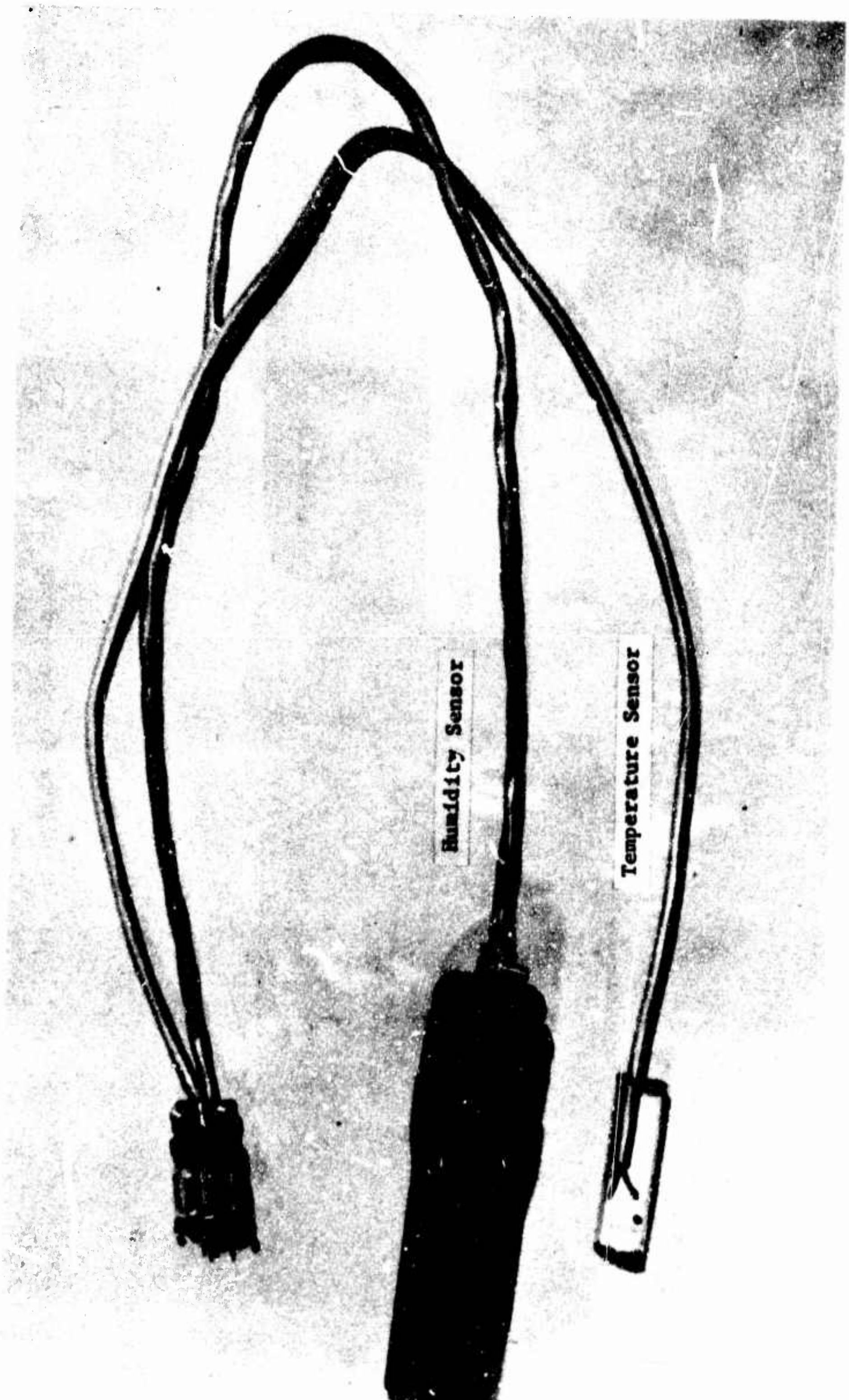

Figure 2. Sensors.

The humidity sensor (Figure 2) is a processed plastic wafer which has an electrically conducting surface layer that is integral with the nonconducting substrate. The surface resistivity exibits a logarithmic decrease with increasing R.H. The sensor is a Phys-Chemical PCRC-11 and has a temperature range of -50°C to 93°C and a temperature coefficient of 0.2% R.H./°C. The univibrator pulse is fed through this sensor and a string of diodes in series with the sensor. The voltage across the diodes is picked off, amplified, and fed to the recording head. The diodes have the effect of straightening out the overall characteristic so that the recorded signal is near linear with R.H.

(3) Batteries. Alkaline cells are used where possible to achieve operation over as wide a temperature range as can be obtained with commonly available energy sources.

The primary power supply needed by this system is a +45-volt battery. A +15-volt source is also needed to supply the univibrator pulsing circuit. Union Carbide can supply an alkaline power pack Y1520 which has 45-volt and 1.5-volt sections. These may be used in series to yield a +47.5-volt battery for increased capacity (life). Two 7.5-volt alkaline rechargeable No. 560 batteries may be used in series for the +15-volt source. These batteries (Figure 3a) may be combined in a single battery pack (Figure 3b) (See Section 2b).

The power cell for the Accutron timer is a 1.32-volt mercury cell commonly used to power the Bulova Accutron No. 214 electric watch and

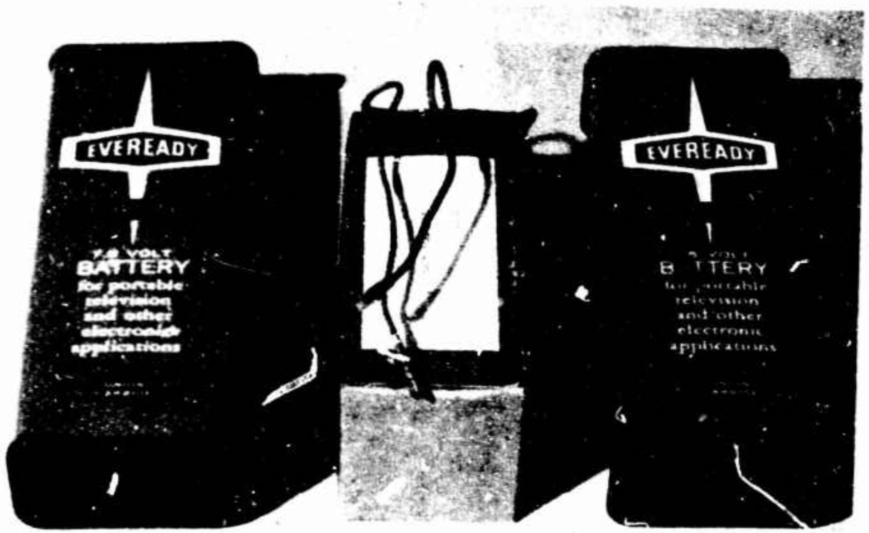

Figure 3a. Batteries.

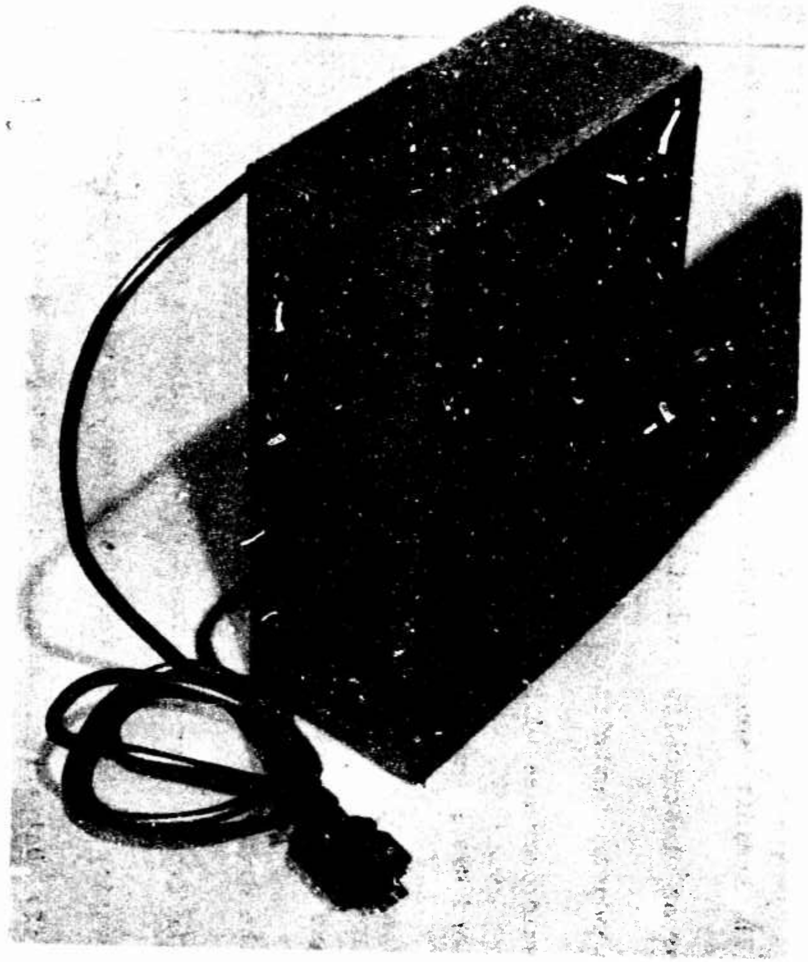

Figure 3b. Battery Pack.

may be obtained at most jewelers. This cell, however, cannot be counted upon to power the timer reliably below -25°C. External alkaline power may be used for timer operation below this temperature. Alkaline cells may be used down to -45°C.

(4) Packaging. A protective frame as is used in the drop height recording system can be used but seems unnecessary if the recorder is adequately protected by cushioning.

The recommended cushioning medium is a minimum of 5 cm (2 inches) of low density 32kg/m^3 (2#/FT^3) polyester polyurethane foam. The resilience of this foam is essentially constant over the temperature range of -30°C to +65°C. At -45°C the foam is approximately three times as rigid as at -30°C and, therefore, a greater cushioning thickness is recommended for expected exposure to this temperature. The optimum static stress level for urethane foam is 1.05 to 3.5 x 10^3 newton/metre^2. If the recorder is cushioned in a number 2-1/2 can case without the use of load spreaders, the resulting static stress is in this range, and satisfactory peak decelerations result. The use of other shipping containers and various cushioning thicknesses may require the use of load spreaders. User experience is the best guide on this point.

(5) Magnetic Tape. A high quality black oxide polyester (mylar) 1/4-inch (6.3-mm) instrumentation tape is recommended for use with this recorder. Tape with a 1.0-mil backing will allow a 30-metre (100-foot) load

on the recorder supply reel. Tape with 1.5-mil backing will provide for more reliable operation because it is less subject to damage (wrinkling, stretching, etc.); however, only 21 metres (70 feet) of it can be loaded on the recorder.

(6) Playback Instrumentation. The following equipment (see Appendix A) is required to retrieve information recorded on tapes used by this system:

(a) A quality tape deck with a constant playback speed and a four-channel playback head similar to the recording head. A playback speed of 1-7/8-in/sec (4.67 cm/sec) has successfully been used but a somewhat higher speed [up to 9"/sec (22.86 cm/sec)] may improve the S/N ratio.

(b) Low noise amplification sufficient to drive display devices.

(c) A high speed display and storage device such as a recording oscillograph or storage oscilloscope. Print-out instrumentation such as described in Appendix A2 could alternatively be used.

d. Theory of System Operation.

Once each hour, a time mark is recorded, and the tape is advanced 1.6 mm (see Figure 4). Signals proportional to the temperature and humidity of the surroundings are recorded on other tracks of the tape approximately 45 seconds after each time mark recording.

When the timer contacts (1) close, the time delay (2) is activated, producing two simultaneous outputs lasting approximately 45 seconds. One

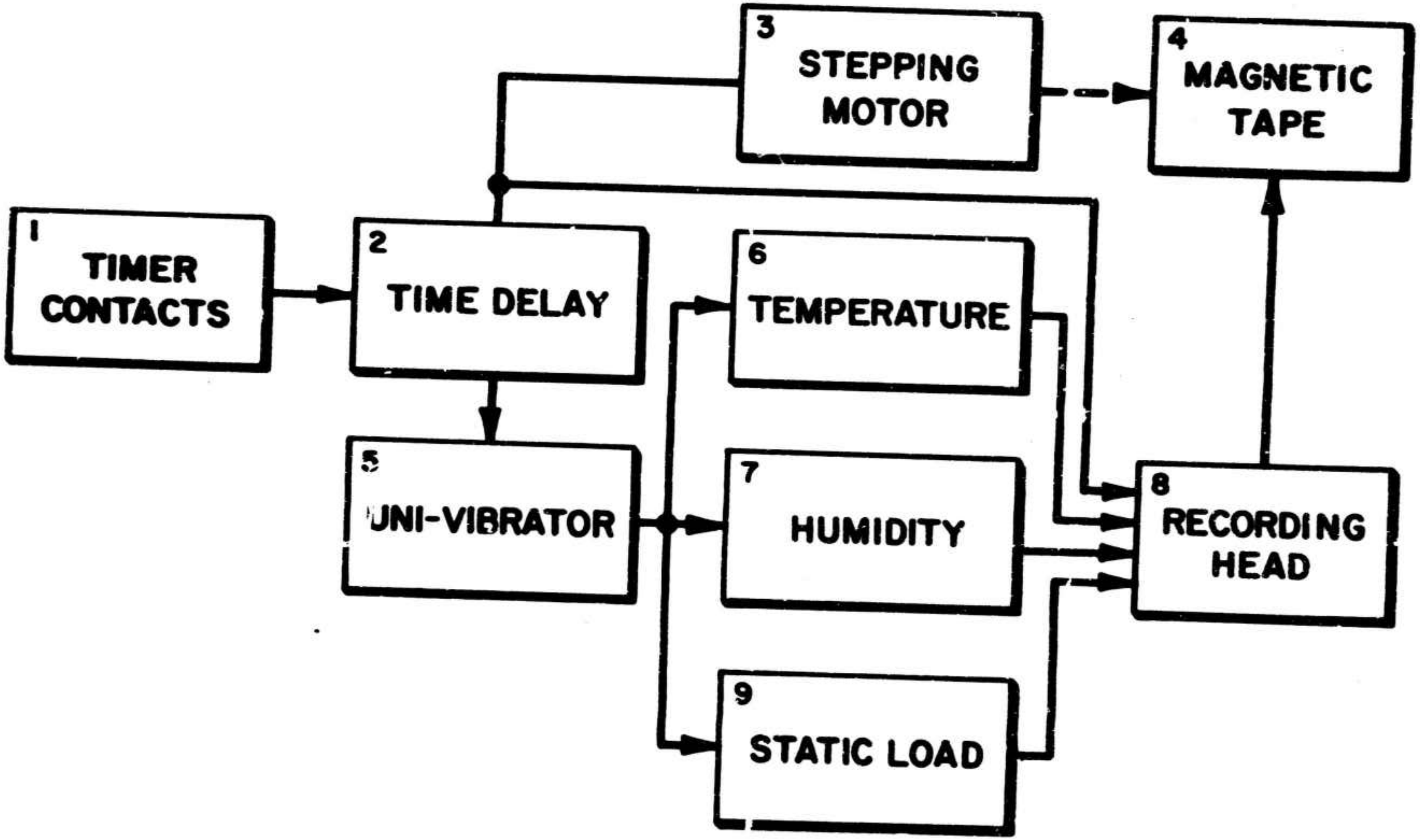

Figure 4. Block Diagram -- Temperature/humidity System.

output is a step from ground potential to +45 volts and is used to generate a time mark on the recording tape (4) and to activate the stepping motor (3) circuitry for advancing the tape 1.6 mm by using the initial positive change to trigger an SCR. The other output is a step from +45 volts to ground potential and is used to activate the univibrator supply (5) for the sensing circuits by employing the trailing (the return to +45 volts) edge as a trigger. The output of this circuit is a 100-msec, +15-volt pulse which supplies the temperature (6) and humidity (7) sensing circuits. Each sensing circuit uses the supplied pulse to yield an output related to the impedance level of its associated sensor. Sensors used with this system are impedance devices that vary predictably with the factor being measured. Sensing circuit outputs are fed through the recording head (8) and thus recorded on magnetic tape (4). The 45-second time delay is necessary to prevent extraneous triggering of the tape advance circuitry and univibrator during the time of timer contact closure (30 seconds duration).

Detailed operation, schematics, and component functions may be found in Appendices C, D, and E.

e. Operating Instructions

The following sections (2 and 3) contain detailed descriptions of system preparation, check-out, and calibration. Prior to initial shipment use, all of these procedures should be followed. For subsequent shipments, less preparation will be necessary and check-out procedures may be abbreviated; however, the calibration procedure should remain intact.

A system that has been correctly prepared and has passed the checks outlined in Sections 2 and 3 may be used for shipment. The system may be sent out after the recorder is loaded with tape (Section 2g) and packaged (Figure 5), and an initial calibration series is made (Section 3). At the conclusion of a shipment, a second calibration series is recommended. The tape may then be removed from the recorder and played back into a suitable display device (Appendix A).

2. Recorder Preparation and Checkout

a. Timer Check (Appendix D, Figure D1, Item 11)

(1) Remove eight screws holding timer case and advance electronics case.

(2) Remove timer from case.

(3) Check for movement of second hand or characteristic hum of Accutron mechanism to see if timer is running.

(4) If not running, jar timer by shaking or slight tapping.

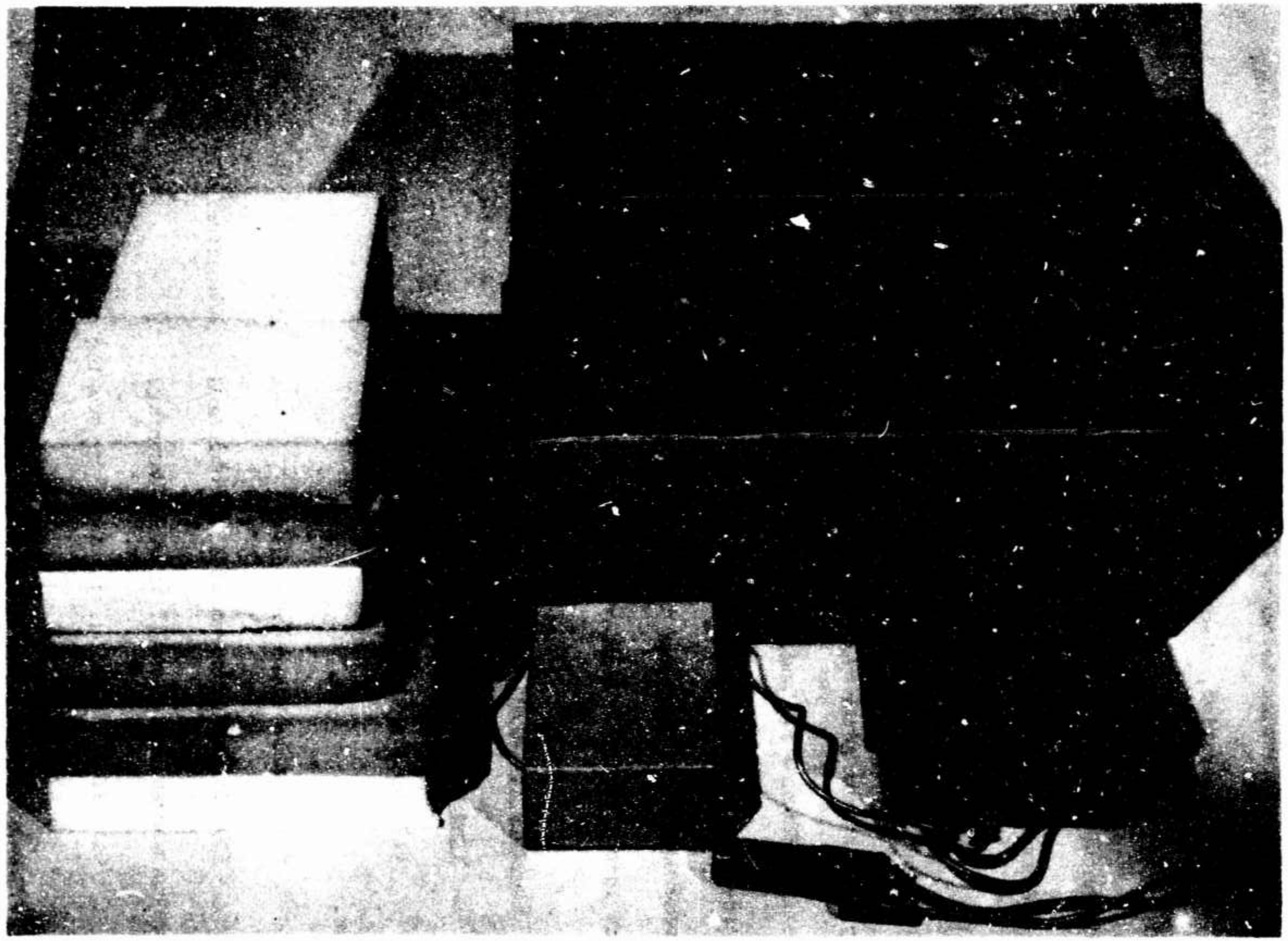

Figure 5. Typical System Packaging.

(5) If still not running, open cell compartment on rear of timer by removing screw-type cover and remove and discard old cell, if any.

(6) Insert fresh cell as indicated.

(7) Start by slight shaking or tapping of timer.

(8) Replace cover, timer, cushioning case, eight screws.

b. Battery Pack and Cable Preparation

A battery pack may be fabricated by inclosing the two series-connected 560 batteries and the Y 1520 battery together in a fiberboard wrap to form a rectangular pack (See Figure 3). A three-conductor power cable about two feet in length should come out of the pack with conductors connected internally to the +47.5-volt point, the +15-volt point and the common (low side of both voltage sources connected together).

The recorder end of the power cable requires the following connections to Amphenol 7-pin connector No. 126-195 (Figure 6, power connector):

TABLE I. BATTERY CABLE CONNECTIONS

Pin	Connection
A*	+7.5 V
B	+45 V or + 47.5 V
C	Common
D	+15 V

*Only used if static load circuitry is included

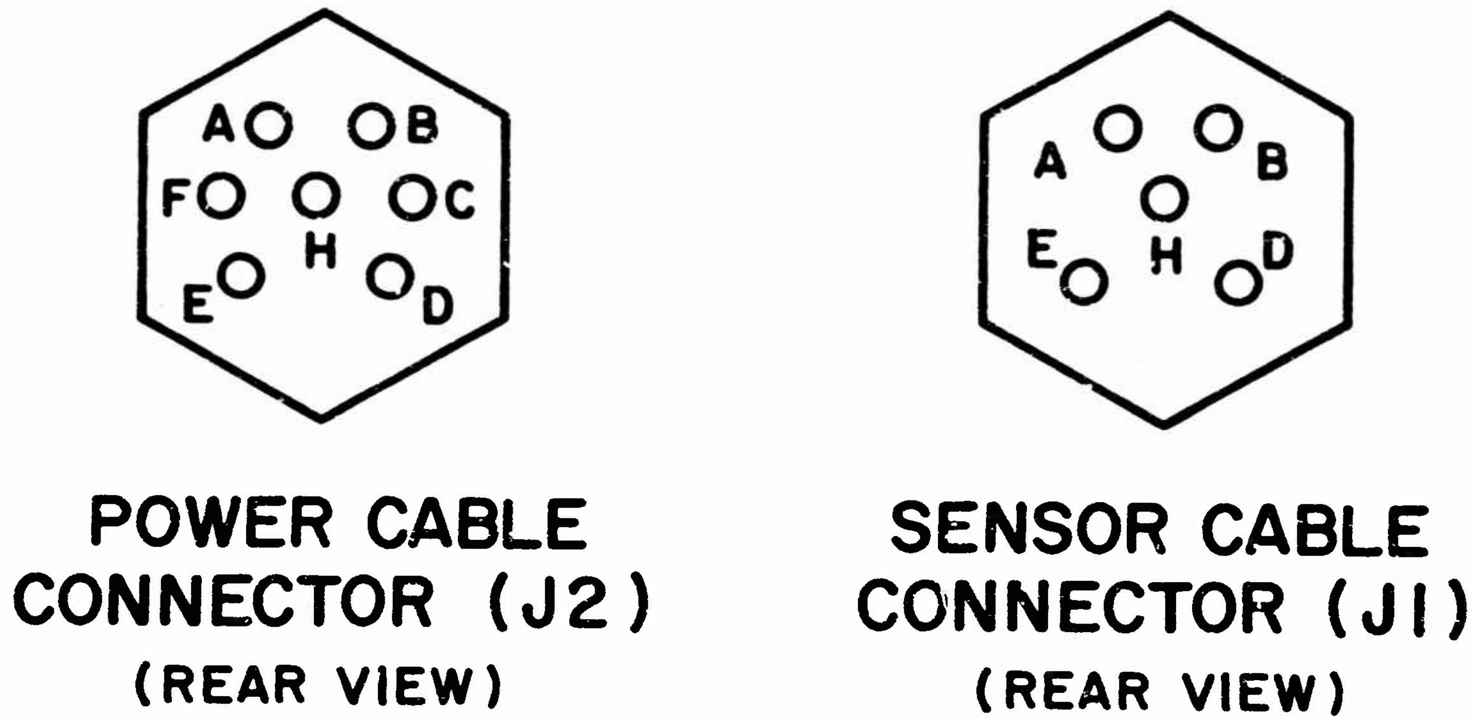

Figure 6. Cable Connectors.

c. Sensor Cable Connections

The humidity and temperature sensors should be connected to the sensor connector by means of 2- and 3-conductor cables, respectively, about four feet long. The following connections should be made to Ampnenol 5-pin connector No. 126-217 (Figure 6, sensor connector):

TABLE II. SENSOR CABLE CONNECTIONS

Pin	Connection
A	Temperature Sensor Common
B	100 ohm Thermistor (free end)
H	3000 ohm Thermistor (free end)
D	Humidity Sensor
E	Humidity Sensor

d. Reel Advance and Timer Circuit

(1) Advance Motor Circuit Check

(a) Momentarily short terminal No. 23* to ground (nearby mounting screw, recorder case, or terminal No. 7). Caution: Avoid electrical contact with any terminal other than that specified in conducting this or any of the following procedures.

(b) If digimotor steps tape reels and recycles within two seconds (approximately) if short is maintained, go to step (2), Timing Circuit Check.

(c) Otherwise go to troubleshooting procedure 1, Table V.

(2) Timing Circuit Check

(a) Temporarily remove time delay lead from point 11 on the terminal board. Short terminal No. 13 to terminal No. 11 for a period of one to three seconds and remove.

(b) If digimotor indexes upon removal of short and will do so again if the procedure is repeated after a wait of at least 10 seconds, go to e, Time Delay and Univibrator Check.

(c) Otherwise go to troubleshooting procedure 2, Table V.

e. Time Delay and Univibrator Check

(1) Reconnect time delay lead to terminal No. 11 and proceed as follows:

(a) Short terminal No. 13 to 14 for one to three seconds.

(b) If digimotor steps tape reels, go to step 2.

*Terminal numbers in Sections d, e, and f refer to Figure 7.

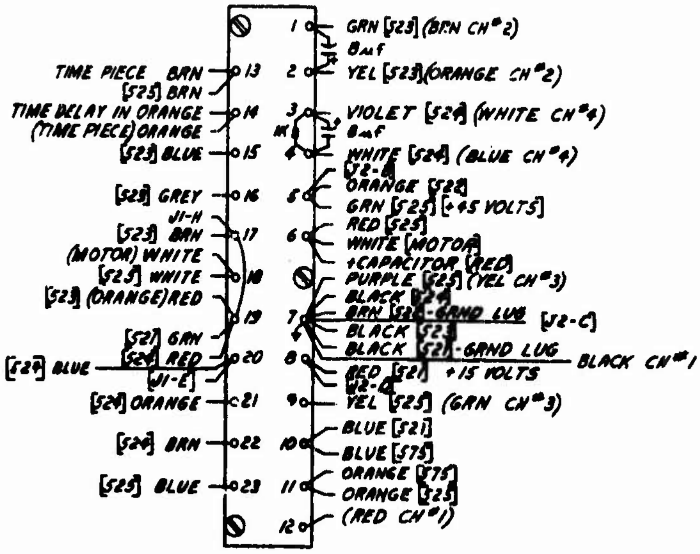

Figure 7. Terminal Board.

(c) Otherwise go to troubleshooting procedure 3, Table V.

(2) Repeat step e(1) while monitoring point 10 with a d.c. voltmeter or oscilloscope.

(a) If point 10 initially goes from V+ (+45 volts) to ground, remains at ground potential for about 45 seconds, and then returns to V+, go to step e(3). (See Figure 8a.)

(b) Otherwise go to troubleshooting procedure 4, Table V.

(3) Repeat step e(1) while monitoring point 19 with an oscilloscope.

(a) If a 100-msec 10-to 15-volt pulse appears at 19 after about 45 seconds, go to f, Temperature and Humidity Function and Range. (See Figure 8b.)

(b) Otherwise go to troubleshooting procedure 5, Table V.

f. Temperature and Humidity Function and Range

(1) Check

Disconnect time delay lead for terminal No. 10 on terminal board. Connect a normally open switch between terminal No. 13 and terminal No. 10. Connect temperature and humidity sensors to the recorder by attaching the sensor connector.

(a) Monitor across terminals 1 and 2 (temperature) with an oscilloscope, and close the normally open switch momentarily. Upon opening, look for a 100-msec rectangular pulse of 50 to 500 millivolts amplitude. If it does not appear, go to troubleshooting procedure 6, Table V.

Horizontal: 5 sec/Div Vertical: 10 v/Div

Figure 8a. Time Delay Output.

Horizontal: 50 msec/Div Vertical: 5 v/Div

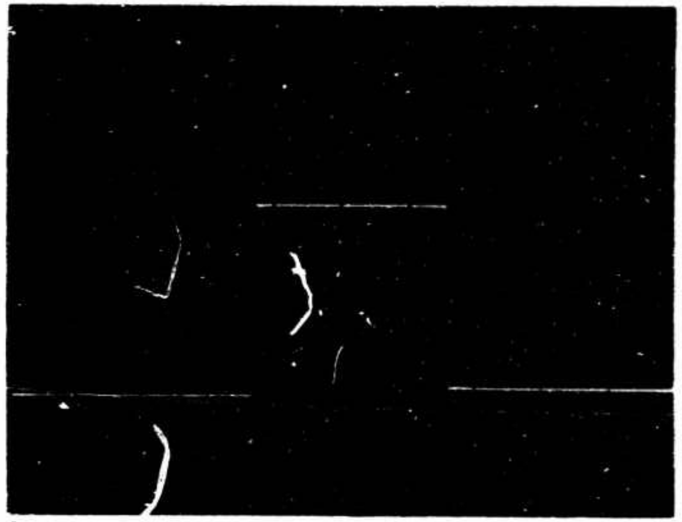

Figure 8b. Univibrator Output.

(b) Monitor across terminals 3 and 4 (humidity) and close switch momentarily. Upon opening, look for a 100-msec rectangular pulse of 50 to 500 millivolts amplitude. If it does not appear, go to trouble-shooting procedure 7, Table V.

Note: Wait at least one minute between tests.

(2) Adjustment

Disconnect sensor cable connector. Remove jumper between terminals 19 and 17. Make sure time delay lead is removed from terminal No. 10. As with the check above, a normally open manual switch should be connected between terminals 13 and 10.

(a) Temperature Adjustment. Connect terminal No. 19 to terminal No. 15. Close the normally open switch between 13 and 10. Open the switch while monitoring across terminals 1 and 2. If no signal appears, adjust R8 (Figure 9a) until switch action produces a signal (Figure 9b). Record the amplitude in millivolts of the resulting pulse and call it V_L. Disconnect 19 from 15 and connect 19 to 16. Close the normally open switch between 13 and 10. Open the switch while monitoring across terminals 1 and 2. Record the amplitude in millivolts and call it V_H. Determine the value of correction C in millivolts from:

$$C = \frac{V_H - 3V_L}{2}$$

If C is positive, increase V_H by adjusting potentiometer R8 (Figure 9a). Check V_H by monitoring across 1 and 2 while closing and opening the normally open switch. Continue to adjust R8 until V_H has increased by C.

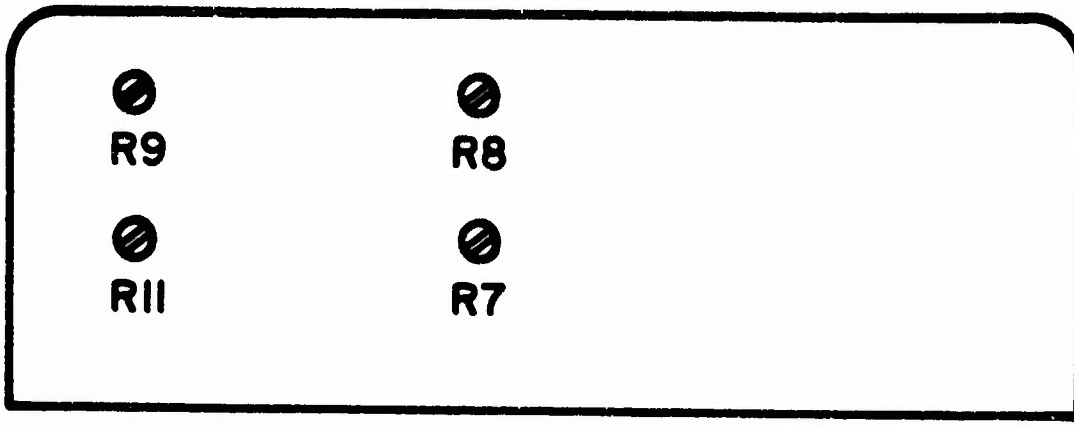

Figure 9a. Temperature and Humidity Adjustment Pots.

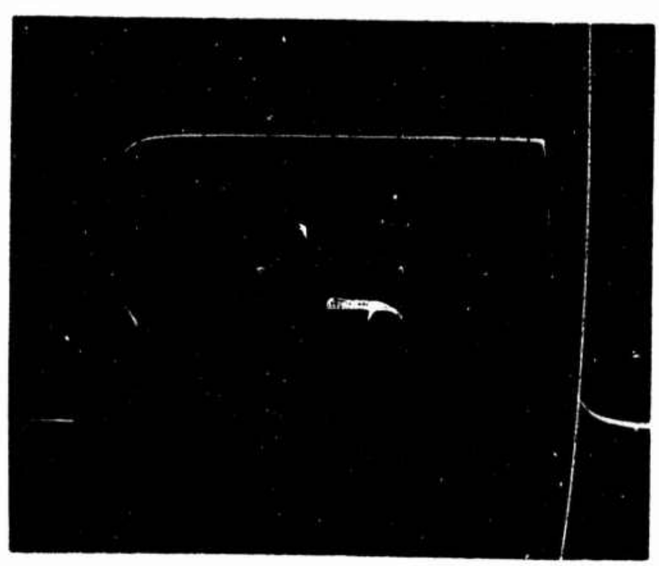

Figure 9b. Head Signal.

If C is negative, decrease V_H by C in the same manner.

The gain may now be adjusted. Adjust potentiometer R9 (Figure 9a) while checking V_H. Set V_H equal to 270 millivolts. Now check V_L by switching jumper back to terminal 15. If V_L is other than 90 millivolts (approximately), recalculate C and readjust R8 and R9. Continue until $V_L \approx 90$ mv and $V_H \approx 270$ mv.

(b) Humidity Adjustment. Connect terminal 20 to terminal 21. Close the normally open switch between terminals 13 and 10. Open the switch while monitoring across 3 and 4. If no signal appears, adjust potentiometer R11 until a signal appears (Figure 9b). Record the pulse amplitude in millivolts and call it V_L. Disconnect 21 from 20 and connect 22 to 20. Close the switch between terminals 13 and 10. Open the switch while monitoring across 3 and 4. Record the amplitude in millivolts and call it V_H. Determine the value of correction C in millivolts from:

$$C = \frac{V_H - 3.76V_L}{2.76}$$

If C is positive, increase V_H by adjusting potentiometer R11 (Figure 9a). Check V_H by monitoring across 3 and 4 while closing and opening the normally open switch. Continue to adjust R11 until V_H has increased by C. If C is negative, decrease V_H by C in the same manner.

The gain may now be adjusted by setting R7 (Figure 9a) while checking V_H. Set V_H = 320 millivolts. Now check V_L by switching jumper back to terminal 21 and triggering the record pulse. If V_L is more than

10 millivolts different than 85 millivolts, recalculate C and readjust R11 and R7. Continue until $V_L \approx 85$ mv and $V_H \approx 320$ mv.

(c) Reconnect time delay lead to terminal 10. Return jumper between 19 and 17. Remove switch between 13 and 10. Remove leads between 19 and 15 or 16 and between 20 and 21 or 22.

g. Recording Tape Considerations

(1) Tape Premagnetization

The unipolar nature of all data recorded by this system permits premagnetization of the recording tape to the saturation level in the direction opposite that of data recording which increases the dynamic recording range by 50% (see Appendix A). All three data tracks of the tape may be premagnetized simultaneously. A tape deck equipped with a 5651 or 5653 Nortronics four-channel head and a slow drive speed (3-3/4 inches/sec (9.5 cm/sec) or 1-7/8 inches/sec (4.76 cm/sec)) can be used in conjunction with a six-volt d.c. battery or power supply. Head terminal leads should be accessible to allow direct application of d.c. current. Channels should be connected in parallel as shown in Table III and supply current attenuated to a level of 9 ma ± 0.5 ma. This level can be precalculated or measured with a d.c. milliammeter connected in series.

TABLE III Premagnetization Connections

	Color of Head Lead	
Channel	Positive Connection	Negative Connection
1	Red	Black
2	Brown	Orange
3	---	---
4	Blue	White

The recording tape should be degaussed with a bulk-type eraser prior to premagnetization. It is suggested that a full 7-inch

(17.88 m) reel should be premagnetized at one time to create a ready supply, eliminate the need for premagnetization before every shipment and to insure "same reel' repeatability between shipments and recorders. Premagnetized reels of tape should be labeled as such and should be protected against exposure to magnetic fields which could cause accidental erasure. The top track of the tape (track corresponding to channel #1) should be indicated and the tape should be wound so that, looking from the top, counter-clockwise rotation of the reel will unwind the tape.

(2) Tape Loading and Unloading

Prior to loading the tape, the tape head and guides should be cleaned with a commercial tape head cleaner or isopropyl alcohol. Head alignment should be checked with a small strip of tape for parallelism with head channels and centering of the tape on the recording area of the head. Adjust if misaligned.

(a) Remove supply reel (bottom reel) and take-up reel (top reel) from reel retainers (Appendix D1, Item 4). To remove reels, it may be necessary to rotate the upper reel retainer in a counter-clockwise direction against the spring tension until upper and lower reel retainers are aligned.

(b) Attach premagnetized magnetic tape to supply reel by pressure-sensitive tape and wind onto supply reel until capacity is reached with care to avoid touching the dull (oxide) surface of the tape. Make sure "up" edge of the tape will be up with respect to recorder deck when loaded on the recorder.

(c) Demagnetize tape head using commercial head demagnetizer.

(d) Attach free end of tape on supply reel onto the take-up reel with pressure-sensitive tape and wind at least one and one-half convolutions of tape around the take-up reel.

(e) Leave a few inches of slack between the supply and take-up reels.

(f) Place supply reel on lower reel retainer (alignment of reel retainers may be necessary) so that supply will be clockwise.

(g) Thread tape around guides and rollers and in front of the tape head (Figure 10).

(h) Turn upper reel retainer at least one complete turn counterclockwise against spring tension and hold.

(i) Remove slack from tape by winding onto take-up reel and slip take-up reel onto upper reel retainer.

(j) Make sure both supply and take-up reels are fully seated in their respective retainers.

(k) Advance the tape a few times to remove slack from the system. The tape should now be loaded as in Figure 10.

(l) To remove the tape, rotate upper retainer counterclockwise until take-up reel can be removed.

(m) Lift take-up reel while holding reel retainer until reel is completely free.

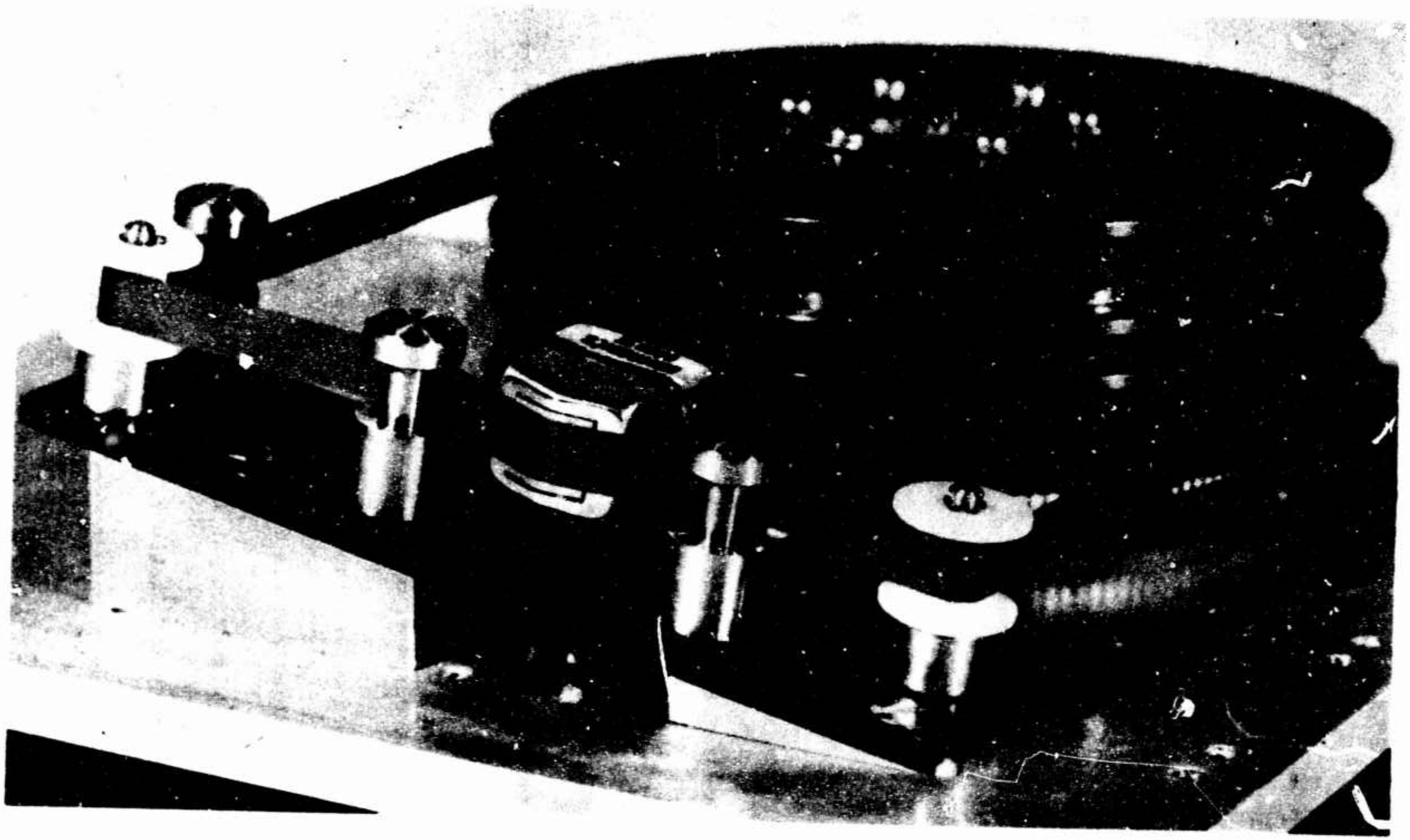

Figure 10. Tape Loaded.

(n) Reel retainer can now be released allowing spring to relax.

(o) Cut tape at point of departure from take-up reel.

(p) Tape on take-up reel can now be transferred to tape deck for playback and analysis.

h. Recording Function Test

(1) Load a short length of tape on the recorder (0.6 metre to 1.5 metre).

(2) Attach a switch between terminals 13 and 14.

(3) Disconnect jumper between terminals 19 and 17. Connect terminal 19 to terminal 15. Connect terminal 20 to terminal 21.

(4) Close switch for one to three seconds.

(5) Wait 90 seconds.

(6) Repeat steps 4 and 5 four times.

(7) Advance tape by shorting point 23 to ground ten times.

(8) Remove connections between 19 and 15 and between 20 and 21. Connect terminal 19 to terminal 16 and terminal 20 to 22.

(9) Repeat steps 4, 5, and 6.

(10) Remove and play back tape.

(11) Check data channels for playback as in Figure 11a.

(12) If there is no output from the temperature channel, go to troubleshooting procedure 8, Table V.

(13) If there is no output form the humidity channel, go to troubleshooting procedure 9, Table V.

Horizontal: 0.1 sec/Div Vertical: 0.2 v/Div

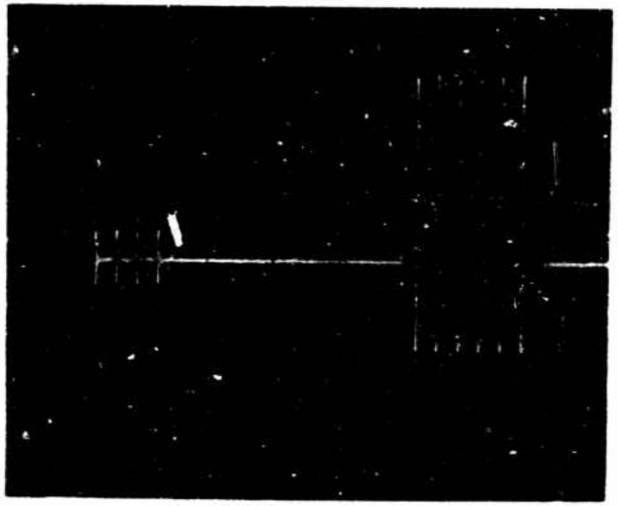

Figure 11a. Function Test Playback (Temperature).

Horizontal: 0.1 sec/Div Vertical: 0.1 v/Div

Figure 11b. Function Test Playback (Time).

(14) Check time channel for output as in Figure 11b.

(15) If there is no output, go to troubleshooting procedure 10, Table V.

(16) Once corrections have been made, repeat above procedures as deemed necessary.

(17) Return jumper between 19 and 17. Remove switch between 13 and 10. Remove leads between 19 and 15 or 16 and between 20 and 21 or 22.

3. Suggested Calibration Procedure

a. Hourly Readings

This procedure requires subjecting the system to a series of temperature and humidity conditions for periods of twenty-four hours for each condition. The number and value of temperature and humidity conditions selected will be determined by what is thought to be required to yield adequate calibration curves and also by what is available in the way of environmental chambers. Four or five points well scattered between -45°C and +60°C and also between 10% RH and 100% RH should be sufficient. A typical schedule is shown below for guidance.

TABLE IV
Typical Calibration Schedule
(24 hours at each condition)

Condition	Temperature (°C)	Humidity (% RH)
1	-18	unknown
2	0	30
3	-1	75
4	22	50
5	38	95
6	60	10

This procedure will normally take about a week to finish.

b. Accelerated Test

A faster version of the above calibration run can be effected. A normally open manual switch should be connected across the timer terminals (points 13 and 14 on the terminal board). Sensors should be left at each set of conditions at least three hours before readings are taken. Readings are taken by closing the normally open switch for a period of two to ten seconds and then releasing. A group of ten or more readings should be taken at each set of conditions. A one-minute wait is required between successive closures of the switch.

This procedure will normally take less than two days to finish.

4. Maintenance and Troubleshooting

a. Routine Maintenance

(1) Batteries

The 45-volt portion of the power pack normally will require replacement after six months of use. The +15 volt supply should be checked after six months. If it has discharged to 12 volts or less, it may be replaced or recharged (see Section 4b). The Accutron power cell normally will operate the timer accurately for a year or more.

When the battery cable is disconnected, the 45- and +15-volt batteries are removed from recorder circuitry and their discharge characteristic becomes that of a battery on the "shelf". In this case, batteries may go up to two years between replacements. For replacement procedures see Section 2, Recorder Preparation and Checkout.

(2) Parts Repair and Replacement

Before and after shipment, check for damaged wiring or parts. Repair and replace as required.

Check should also be made for corrosion of recorder parts. Removal of oxide buildup where detected is called for except where excessive buildup may require replacement of parts.

b. Battery Charging

Charging of alkaline secondary batteries requires voltage limited taper current. Check with battery manufacturers for appropriate charging equipment and procedures.

c. Troubleshooting Procedures

Before any of the below procedures are undertaken, check for the following minimum acceptable voltages with respect to recorder ground: +40 volts at terminal board point 5 and +10 volts at terminal board point 8. If any of these voltages are not available, the probable cause is either a battery or wiring problem, possibly at the connector. Make sure the connectors are securely mated.

A low voltage normally indicates a low battery. Disconnect the battery from the recorder and check its voltage; if it is still low, replace the battery.

No voltage indicates an open or short in the wiring or connector. Disconnect the connector and check wiring with a resistance meter for continuity and shorts. Repair or replace any wiring or connector found faulty.

If neither battery nor wiring is at fault, a circuitry problem is indicated. The appropriate circuit should be investigated for shorts or faulty components (check transistors first).

If all required voltages are available to the recorder, the procedures listed on the following pages may be used to locate and eliminate recorder malfunctions. Operation and voltage checking procedures will require power; thus, when undertaking such procedures, the battery cable must be connected to the recorder.

When conducting continuity and resistance checks or when making repairs, power must be removed from the recorder by disconnecting the battery cable from the recorder and discharging the 1000 μf capacitor (C2) through a resistor (1K or larger).

Repair of circuits in this recorder requires removal of the potted circuit board from its potting case and the cutting away of potting compound around the defective component, desoldering and removal of the component, replacement and resoldering, and return of the potted board to its case. The cavity left in the potting compound may be filled with fresh compound.*

*Dow Corning SYLGARD 184 was used.

TABLE V

Troubleshooting

Malfunction	Test	Abnormal Indication	Repair Method	Reference Drawings
1. Digimotor will not index when point 23 is shorted to ground.	a. Check continuity from terminal board to digimotor and capacitor C5.	Open	Repair wiring	D2a; D3a; D1, Items 13, 14, 16
	b. Check C5 when disconnected from circuit	Short, leaking or open	Replace C5 (1000 μfd)	D2a; D3a, D1, Item 13
	c. Check resistance from point 18 to recorder ground	Less than 3K ohms, both directions	Replace TR4 (2N3054)	D2a; D3a, D1, Items 16, 17
	d. Remove TR1 and short point 23 to ground	Motor steps	Replace TR1 (2N404A)	D2a; D3a; D1, Item 17
2. Digimotor does not index when point 13 is shorted to 11 but will if point 23 is shorted to ground.	Remove SCR and check	Cathode to anode short or other defect	Replace SCR (2N1595)	D2a; D3a; D1, Item 17
3. Digimotor does not index when point 13 is shorted to point 14	a. Check continuity of wiring from points 5, 14, 11 to time delay board	Open or short to ground	Repair wiring	D2b; D3b; D1, Item 6
	b. Check Q1 on time delay board	Collector-emitter short or junction short or open	Replace Q1 (2N3053)	D2b; D3b; D1, Item 6

TABLE V - Continued

Malfunction	Test	Abnormal Indication	Repair Method	Reference Drawings
	c. Check Q2 on time-delay board	Collector-emitter short or junction short or open	Replace Q2 (2N1132)	D2b; D3b; D1, Item 6
4. Time delay waveform does not appear at point 10 when point 13 is shorted to point 14 but digi-motor does index	a. Check C1 when disconnected	Short, leaking or open	Replace C1 (1000 μfd)	D3b; D1, Item 30
	b. Check Q3 on time delay board	Collector-emitter short or junction short or open	Replace Q3 (2N3054)	D2b; D3b; C1, Item 6
5. Nc univibrator pulse output at the end of time delay input	a. Check continuity - univibrator to terminal points 7, 10, 19, 8	Open	Repair wiring	D2c, D3c, D1, Item 6, 16
	b. Check Q2 on univibrator board	Collector-emitter short or junction short or open	Replace Q2 (2N3638)	D2c; D3c; D1, Item 6
	c. Check Q1 on univibrator board	Collector-emitter short or junction short or open	Replace Q1 (2N2714)	D2c, D3c, D1, Item 6
6. Univibrator pulse does not yield temperature channel output	a. Check continuity, temperature board to points 19, 1, 2, 17, 16, 15	Open	Repair wiring	D2d; D3d; D1, Item 34, 16
	b. Check resistance of R8, R9	Open	Replace pot	D2d; D3d; D1, Item 34
	c. Check Q1, D1, D2 on temperature board	Collector-emitter short or junction short or open	Replace Q1 (2N7219) D1 (1N746) or D2 (1N823)	D2d; D3d; D1, Item 34

TABLE V - Continued

Malfunction	Test	Abnormal Indication	Repair Method	Reference Drawings
7. Univibrator pulse does not yield humidity channel output	a. Check continuity, humidity board to points 19, 3, 4, 20, 21, 22	Open	Repair wiring	D2e; D3e; D1, Item 34, 16
	b. Check resistance of R7, R11	Open	Repair pot	D2e; D3e; D1, Item 34
	c. Check Q4, D1, D2, Q2, Q3, Q1, D5, D4, D5	Collector-emitter short or junction short or open	Replace Q4 (2N2219), D1 (1N746), Q2 (2N3156), Q3 (2N2484), D3, D4, D5 (1N914) Q1	D2e; D3e; D1, Item 34
8. No temperature channel playback	a. Check continuity between temperature board and head	Open	Repair wiring	D2d; D1, Item 16
	b. Check resistance across head leads of temperature channel	Short or open	Replace head (#5653)	D1, Item 7
9. No humidity channel playback	a. Check continuity between humidity board and head	Open	Repair wiring	D2e; D1, Item 16
	b. Check resistance across head leads of humidity channel	Short or open	Replace head (#5653)	D1, Item 7
10. No time channel playback	a. Check continuity of wiring from tape head to motor and time circuit board	Open	Repair wiring	D1, Items 16, 7, 17

TABLE V - Continued

Malfunction	Test	Abnormal Indication	Repair Method	Reference Drawings
	b. Check resistance across head leads	Open or short	Replace head (#5653)	D1, Item 7
11. Recorder advance on trailing edge of time delay signal	Check connections on terminal board and on circuit boards	Cold solder joints or loose wiring on terminal board or circuit boards	Repair connections	D2f; D2a; D3b, D1, Items 16, 6, 17
12. Univibrator recovers very slowly	Check components in input circuitry of univibrator	Open resistor, open or shorted diodes	Replace defective component	D2c; D3c, D1, Item 6
13. Advance on trailing edge of univibrator signal	Check connections on terminal board and circuit board	Cold solder joints or loose wiring	Repair connections	D2f; D2a; D2b; D2c; D1, Items 16, 6, 17
14. Temperature channel cannot be adjusted	Check continuity between center taps of R9 and R8 and their end terminals	Open	Replace defective potentiometer	D2d; D3d; D1, Item 34
15. Humidity channel cannot be adjusted	Check R7 and R11 continuity - center tap to end terminals	Open	Replace defective potentiometer	D2e; D3e; D1, Item 34
16. Low temperature non-advancement	Check time delay and advance electronics boards for cold solder joints	Opens or near-opens due to cold solder joints	Repair joints	D3a; D3b; D1, Items 6, 17

5. Static Lo.:

a. Description of System:

The fourth channel of the temperature/humidity recorder can be used to record the static compressive load experienced by a package. Using BLH C2M1 load cells incorporated into a force plate load sensing structure and operational amplifier signal conditioning circuitry, this system allows recording of loads in the 0- to 27,000 newtons (6000-pound) range.

Four load cells are located within vertical struts positioned in the corners of and between two 32.5-cm-square 2.5-cm-thick aluminum honeycomb panels. The C2M1 load cell is rated at 9000 newtons (2000 pounds) and weighs less than 0.9 kg so that four cells can handle up to 35,000 newtons (8000 pounds) and have a total weight of less than 0.36 kg. The structure weight including load cells is approximately 9.45 kg (21 pounds), making the total system weigh in the vicinity of 15.8 kg (35 pounds). The minimum system dimensions are limited by the size of the load-sensing structure and are approximately 19 x 33.6 x 33.6 cm (7-1/2 x 13-1/4 x 13-1/4 inches). The load-sensing member itself is a stainless steel diaphragm to which compressive load is applied by a rubber washer from a load button. A concentric diaphragm strain gage bridge is bonded to the diaphragm. Each leg of the bridge is 350 ohms. The load cells are connected in series as shown below and electrically mated to the recorder via a flexible cable terminated by an Amphenol No. 126-217 5-pin connector (see Figure 12). An additional Amphenol No. 126-218 must be mounted on the recorder case to mate with the load cell cable.

TABLE VI. Load Cell Connections.

Load Cell Lead Color	Cell #1	Cell #2	Cell #3	Cell #4
Red	Terminal B			
Black	Terminal D			
Green				
White				
				Terminal H

The static load circuitry utilizes the univibrator pulse (see Section 1d) to excite the load cell network connected in the feedback path of a low-power IC operational amplifier (RCA CA 3078AT). An additional amplifier follows to boost the signal level up to record level. Dual power is supplied to the amplifiers by tapping off +7.5 volts from the +15-volt supply as a reference and using +15 and recorder common as V+ and V-. The +7.5-volt tap should be run to terminal A of the battery connector and from there to terminal No. 11 on the recorder's terminal board. The differential output voltage of the second amplifier (terminal 12) with respect to terminal 11 is used for recording. As is the case with the temperature and humidity channels, the magnetic tape should be premagnetized to the saturation level in the opposite direction from data recording. Adjustment potentiometers are located on the static load

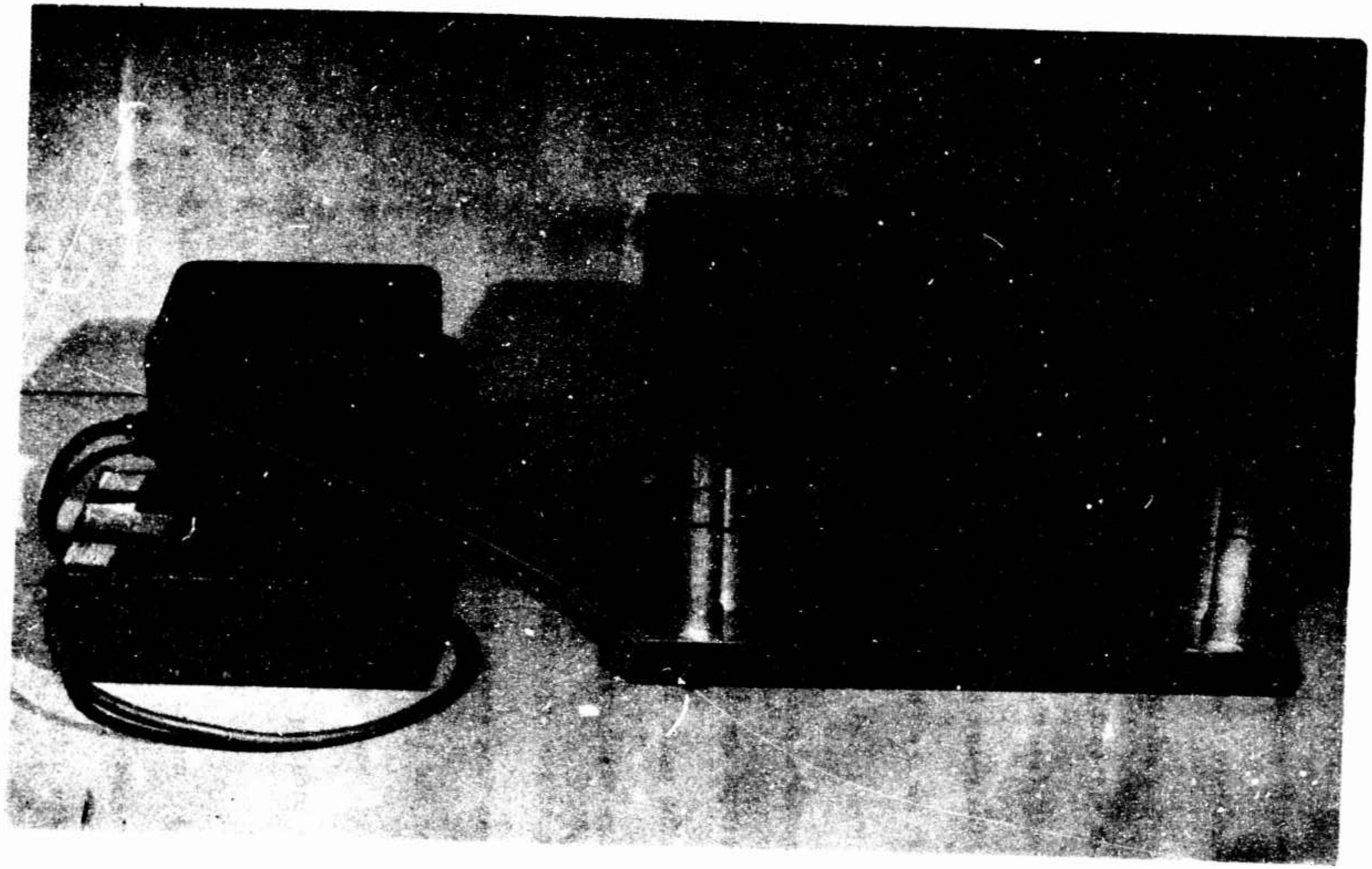

Figure 12. Load Structure.

circuit board for d.c. offset and signal offset. A signal offset setting of -50 mv will cause the overall load/playback characteristic to become near-linear from the origin.

b. Theory of Operation:

(1) A +15-volt pulse from the univibrator is fed into the static load circuit (see Figure 13).

(2) The pulse is reduced to 4.8 volts by zener Z1 (referenced to +7.5 volts as are the rest of the static load circuit signal levels).

(3) The 4.8-volt pulse is fed across balancing resistors R2A, R2B, and balancing signal from potentiometer P1 is fed to the positive input of operational amplifier A1.

(4) The pulse is simultaneously fed through the load cell strain gage bridge which is connected so that its output is across the feedback path of the amplifier A1.

(5) As long as the resistance ration of the balancing leg is equal to that of the load cell leg, no output appears.*

(6) If, however, these ratios are not equal, an output occurs. When this imbalance is caused by compression of the load cells, the output is directly proportional to the static compressive load.

(7) Any output of A1 is fed on to inverting amplifier A2 which has a gain of about 25.

(8) The output of A2 is fed through R7 to the record head.

*d.c. offset must be nulled by the 100K P2 potentiometer.

c. Instructions:

Prior to field use of the static load system, the following adjustment procedure should be undertaken with the recorder activated and the static load sensor cable connected. Potentiometers are located on the static load circuit board (see Figure 14).

(1) Adjust the d.c. offset by monitoring across terminals 11 and 12 and turning the 100K potentiometer adjustment screw until the output is zero.

(2) Disconnect the time delay lead from terminal No. 10.

(3) To generate univibrator pulses, short point 13 to point 10.

(4) Adjust the 1K potentiometer until you get the desired pulse out under no-load conditions. A -50 mv pulse with respect to the static load reference will efficiently linearize the overall load/playback characteristic.

(5) Reconnect time delay lead to terminal No. 10.

The static load structure will fit inside a fiberboard container with minimum dimensions of 19 cm x 33.6 cm x 33.6 cm. The container should be constructed so that all of the load on the package is borne by the static load sensing structure. The recorder should be prepared and checked out as in Section 2, above, and a calibration series should be run prior to and following shipment. The system may be calibrated by subjecting the load sensing structure to a series of load levels using a compression tester such as a Tinius Olsen Universal Testing

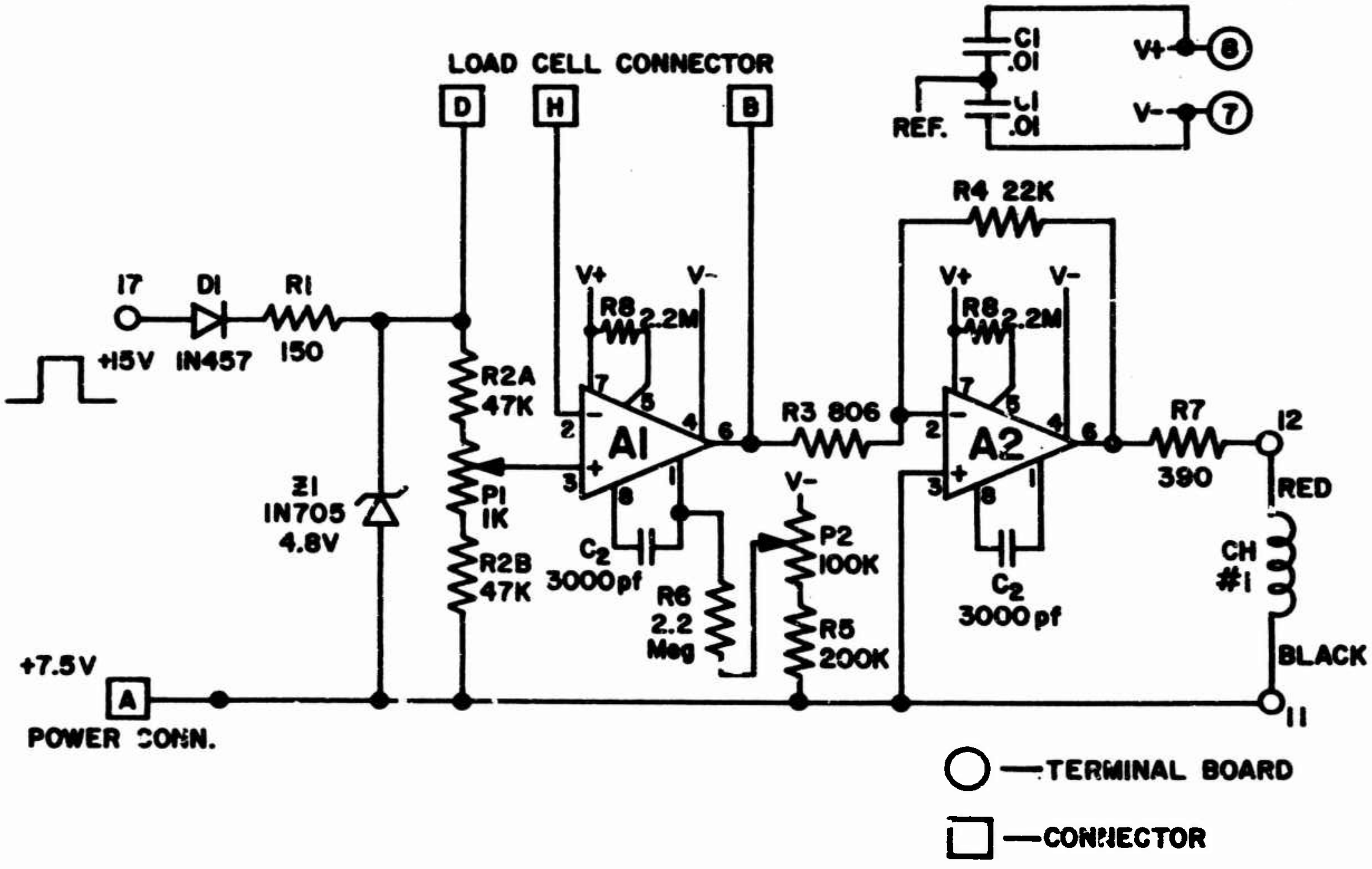

Figure 13. Static Load Schematic.

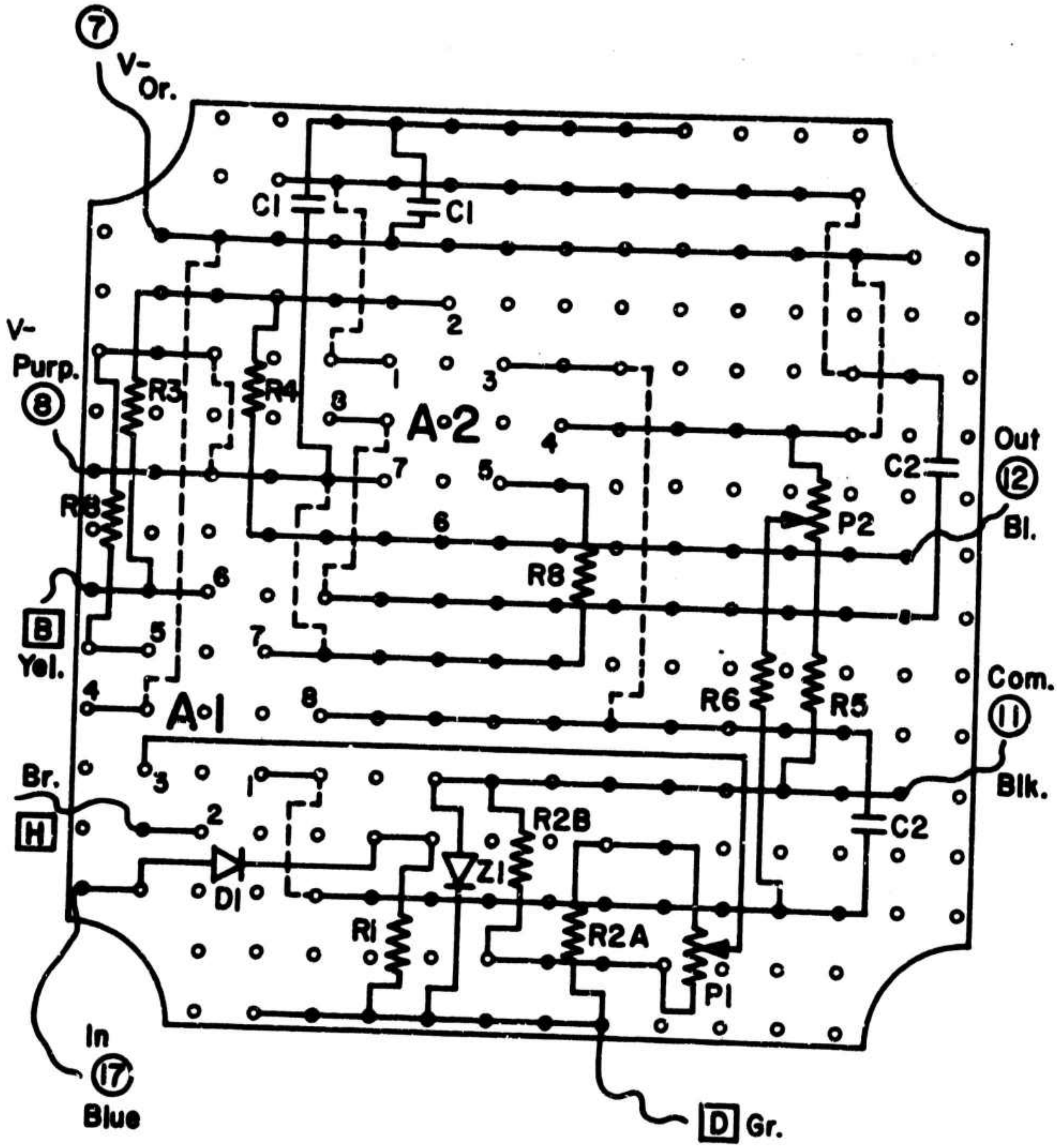

Figure 14. Static Load Board

Machine and activating the recording circuitry a number of times at each level. One-thousand-pound (4450-newton) increments between levels from 0 to 7000 pounds (31,200 newtons) with ten readings at each level should be adequate.

On playback, a calibration curve can be drawn from calibration data and shipment loads determined by reference to the curve.

d. Troubleshooting

Before troubleshooting the static load circuit, check the condition of the batteries (Section 4.c.) and verify time delay/univibrator function (Section 2.e.). Cause-to-effect reasoning can be used to pinpoint circuit faults found to be associated with the static load circuit. Tracing of the signal from input to the point where its appearance departs from normal localizes the search. Some of the more probable malfunctions are tabulated below.

Symptom		Probable Cause	Remedy
1. No output	a.	Open on static load board	Eliminate open.
	b.	Wiring open	Repair wiring.
	c.	IC amplifier failure	Replace amplifier (CA3078AT).
2. Output at positive or	a.	Open in load cell network	Repair wiring or connector.
negative limit	b.	Open on static load board	Eliminate open.
	c.	Power supply open	Repair wiring or connector.

	Symptom	Probable Cause	Remedy
3.	Output too high	4.8V Zener failure	Replace Z1 (1N705).
4.	Oscillation	C2 open	Repair connections or replace C2 (3000pF).
5.	Output drifts excessively	Poor C2 connections	Resolder C2.

6. References

Gertel, M. and Franklin, D., "Determination of Container Design Criteria," U.S. Army Natick Laboratories Report 67-50 GP, January 1967.

Nickerson, C. L., "The Drop Height Recording System - A User's Guide," U.S. Army Natick Laboratories Report 72-72-GP, February 1972.

O'Sullivan, D., "NLABS Shipping Hazards Recorder Statu[illegible] [illegible]uture Plans," The Shock and Vibration Bulletin 39, part 6, pp. [illegible] Ma[illegible] 1969.

Sipin, A. J., "Final Report; Contract DAAG17-67-C-0168, Packaging Exploratory Development," prepared for U.S. Army Natick Laboratories, January 1969.

Venetos, M. A., "Development of Velocity Shock Recorder for Measurement of Shipping Environments," The Shock and Vibration Bulletin 36, part 6, pp. 173, February 1967.

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7. Appendices

Appendix A: Data Retrieval Techniques

Appendix B: Recording-Playback Theory and Curves

Appendix C: Operation of T/H/(L) Recorder Electronic Circuitry

Appendix D: Drawings

Appendix E: Component Function Tables

Appendix F: Reference List of NLABS Drawings

APPENDIX A

Data Retrieval Techniques

1. Manual Techniques

The playback of a pulse recorded on motionless magnetic tape will appear as a pulse doublet (Figure A1) on a display device. The polarity and peak amplitude of the doublet prior to the polarity reversal is related to the polarity and peak amplitude of the original signal. Provided that the playback instrumentation is not changed, similarly polarized inputs will yield similarly polarized outputs and a change in input polarity will cause a change in output polarity.

Shipment information tapes should be played back on a suitable four-channel tape deck at 1-7/8 ips (4.76 cm/sec) and amplified sufficiently to drive a display device for visual records. A four-channel recording oscillograph is desirable for simultaneous tracing of all channels; however, channels may be traced separately and then related to one another. If calibration series have been run, peak amplitudes of pulse doublets in the series should be measured and average values calculated for groups of equal input. A calibration curve for each sensor can then be determined relating playback pulse amplitude to environmental factor. Shipment data estimation can then be made by measurement of playback amplitude of shipment pulses and referral to the calibration curve for the corresponding sensor. The timing channel record provides a means of determining the exact hour of data relative to the start of the shipment.

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Horizontal: 0.2 msec/Div Vertical: 0.2 v/Div

Figure A1. Playback Waveform.

A count of the timing pulse from start of shipment to the data equals the hour of data occurrence. Time-temperature and time-humidity plots can be determined from the above information.

The oscilloscope traces (Figure A2) show playback of a representative calibration series and shipment data from the same recorder. Calibration curves (Figures A3 and A4) can be drawn from this data using average values of playback pulse amplitude. A time plot (Figure A5) can then be determined.

2. Automated Techniques

Automated systems may be devised for read-out data on shipping information tapes. Such a system is in operation at USANLABS (Figure A6).

Timing pulses are counted and the total is available for print-out with data. When environmental data occurs, pulse peak amplitude is temporarily stored for all three channels. Analog to digital conversion is performed on the data for each channel in turn. The data initiates a line of print-out which consists of the time pulse total, temperature, humidity and (if used) static load.

The output of the A.D.C. could conceivably input a digital recorder for generating input tapes for a digital computer. Programs could then be written for the analysis of raw data.

Horizontal: 0.2 sec/Div Vertical: 0.2 v/Div

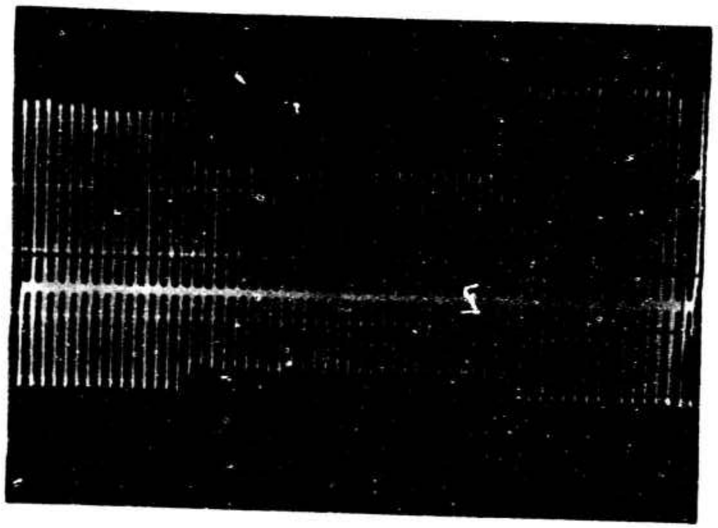


Figure A2a. Calibration Playback.
(22°C, 4°C, 38°C)

Horizontal: 0.2 sec/Div Vertical: 0.2 v/Div

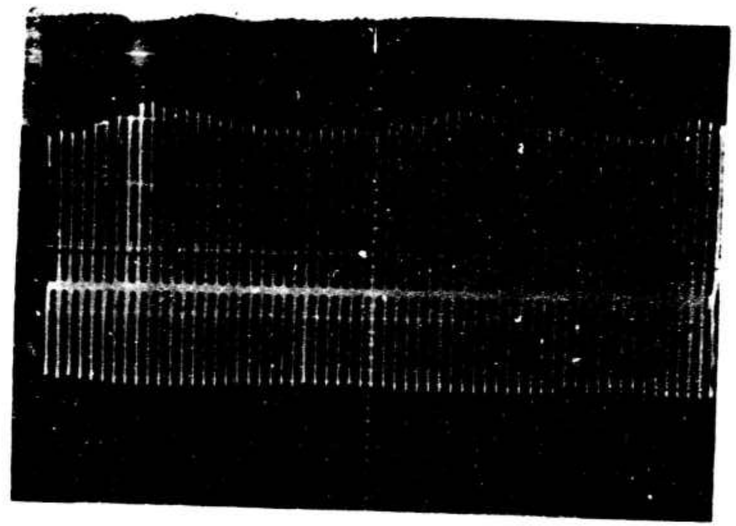


Figure A2b. Shipment Playback.

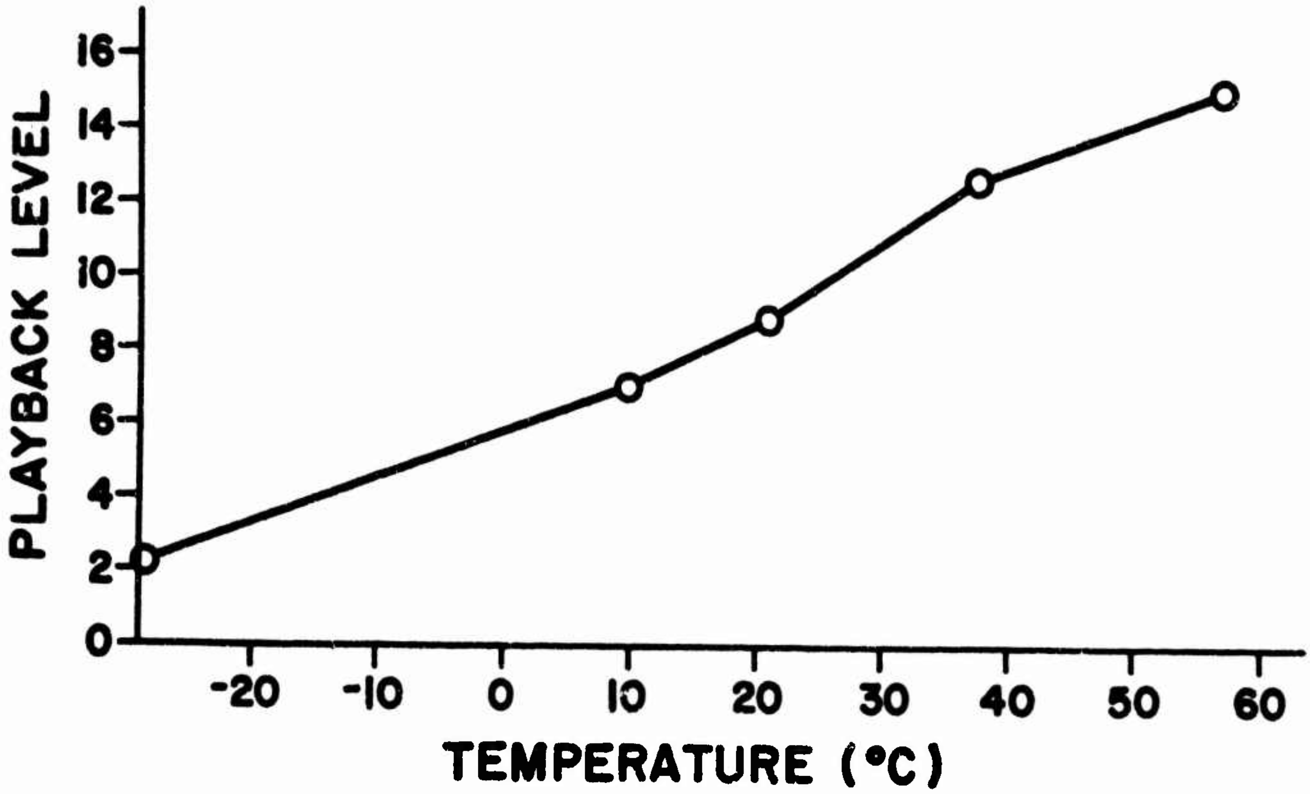


Figure A3. Temperature Calibration Curve.

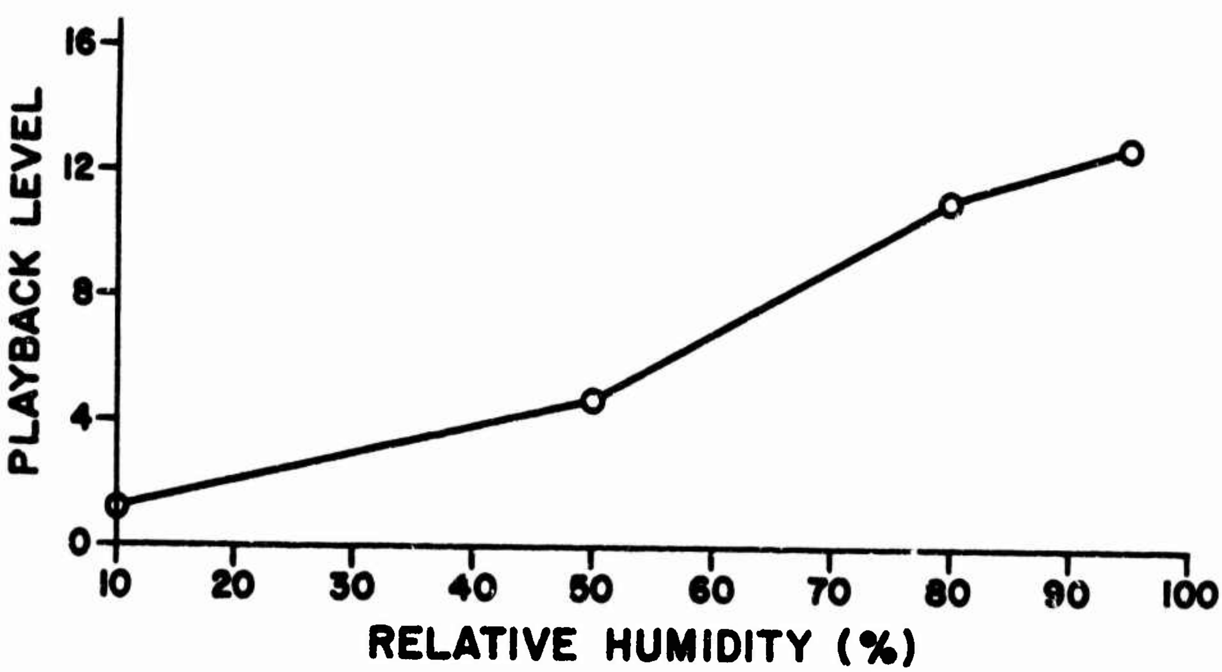


Figure A4. Humidity Calibration Curve.

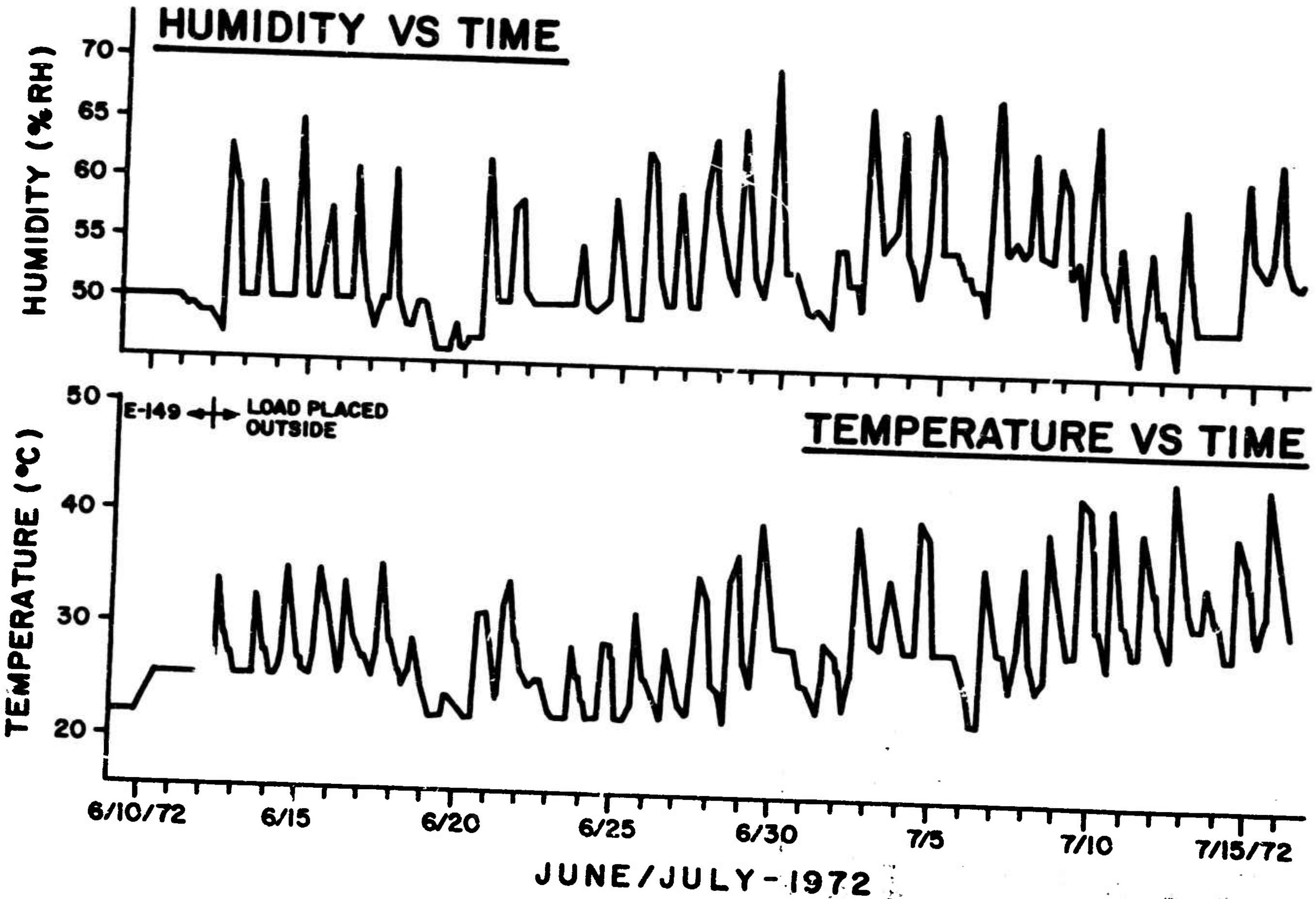
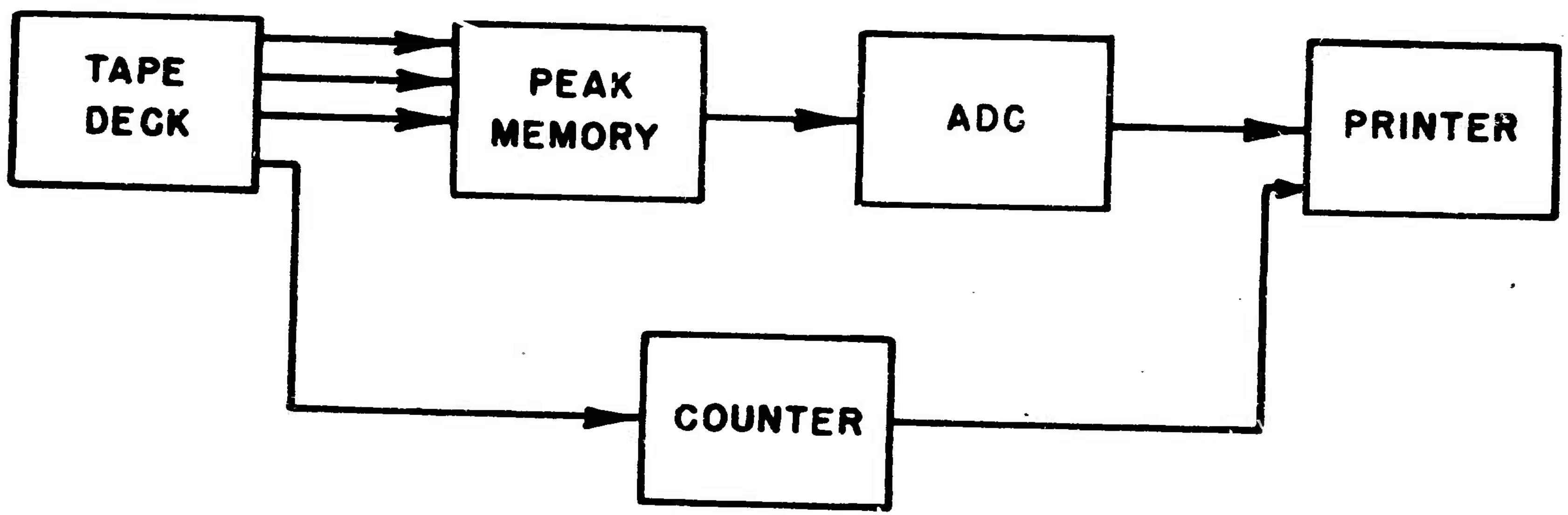


Figure A5. Time/Temperature and Time/Humidity Curves.



SIMPLIFIED BLOCK DIAGRAM
NLABS READ-OUT INSTRUMENTATION

Figure A6.

APPENDIX B

Recording-Playback Theory and Curves

1. Recording

Recording on unbiased motionless magnetic tape results in a magnetized area of tape approximately the size and shape of the recording head gap for each input pulse. The amplitude of the residual magnetism on that area after removal of the input is a nonlinear function of peak input current provided there is no polarity reversal of input current during recording. The function (tape magnetization curve) is dependent upon both tape and head characteristics.

Premagnetization of tape at the saturation level and subsequent recording in the opposing direction will result in a tape premagnetization curve similar to that of unpremagnetized tape but with a useful dynamic range approximately one and one-half times as great; however, use of premagnetization precludes bidirectional recording.

Amplitude errors at record time can result from a variation in tape magnetization due to non-uniformity of particle density, dispersion or size in the tape emulsion. Amplitude errors can also result from tape tracking errors, tape to tape head distance fluctuations and surface smoothness variations along the tape.

Amplitude errors can be reduced by using a tape head with a large head gap, by use of a pressure pad at the tape head, and by precision in the guidance and positioning of the tape during recording. The use of a head with a longer gap produces longer signals impressed on the tape increasing the volume of oxide contributing to the recorded signal

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tending to decrease errors due to non-uniformity of the emulsion. The larger head gap also decreases the error due to fluctuations in tape to tape head distance, since this is a function of the ratio of tape to tape head distance and wave length. The use of a pressure pad at the recording head reduces error resulting from random tape motion and surface smoothness variations.

2. Playback

When recorded data is passed over a suitable playback head, a voltage is induced in that head proportional to the rate of change of magnetic flux associated with the recorded pulse. The resulting output pulse doublet will have an initial polarity corresponding to that of the recorded pulse and its peak amplitude in that polarity will be proportional to the amplitude of the recorded pulse. The overall recording-playback characteristic curve is a function of the head and tape used in recording, the playback head, playback speed, and tape premagnetization used, if any. Curves relevant to NLABS recording system follow (Figure B1).

TABLE B 1
Characteristic Curves

Curve	Model Recording Head (Nortronics)	Gap Length (mils)	Premagnetization	System
1	5651	0.5	No	Drop Height
2	5651	0.5	Yes	Acceleration
3	5653	0.1	No	--
4	5653	0.1	Yes	T/H/(L)

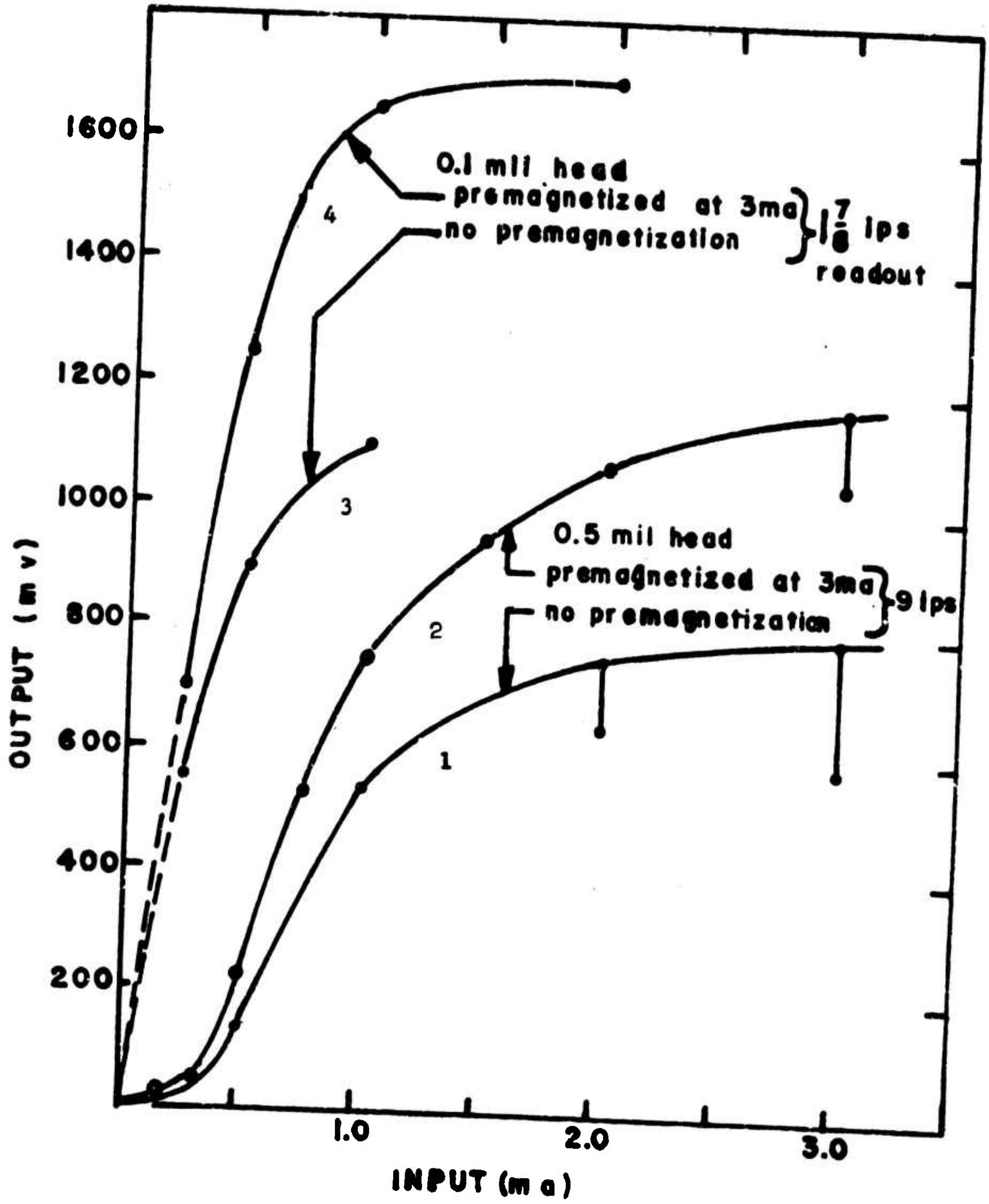


Figure B1. Recording Characteristic Curves.

The lower part of Curve #1 is used for the drop height recording system to take advantage of its similarity to a squaring characteristic in this region. System inputs are proportional to velocity and the square of velocity is proportional to drop height (h); therefore, outputs should be proportional to drop height. For edge and corner drops $V_x^2 + V_y^2 + V_z^2 \alpha h$; therefore, indicated drop heights for separate channels should be added to yield resultant drop height. Polarity sensing is desired for drop height and input range is only four to one, thus premagnetization is not used. The drop height system is susceptible to shock-related scatter of data. The wide-gap head is used to keep scatter to a minimum.

Curve #2 is used from the origin up to near saturation level for the acceleration recording system. The wide-gap head is used for the shock environment, and premagnetization is used with special electronic linearization to obtain a 200 to 1 dynamic range while minimizing error over the entire range.

Curve #3 may be used with systems that are not subjected to shock during the recording process. It offers wide linear dynamic range and bipolar recording capability.

Curve #4 is used for the T/H/(L) recorder system. A narrow-gap head may be used because this system has little shock-related error and the narrow-gap yields a wider linear dynamic range. Premagnetization is used to extend that range since the recording is done in only one polarity.

APPENDIX C

Operation of T/H/(L) Recorder Electronic Circuitry

(Refer to drawings in Appendix D, Figure D3)

A time mark is recorded and the tape advanced once each hour through action of the Accutron timer. The timer also initiates a time delay signal the trailing edge of which activates the univibrator. The univibrator output energizes the temperature, humidity, and (if used) static load measuring circuits with a 100 msec +15 v pulse. The outputs of these circuits which are made proportional to the environmental factors being measured by utilizing impedance changes of their respective sensors are recorded on the remaining three channels of the magnetic tape. Action of the recorder circuitry is delineated below.

1. Timing Circuit and Univibrator

The timing channel records one pulse every hour. The sequence of events in the timing channel is as follows (refer to Figure D3a):

1) Once each hour, contacts of timepiece close shorting point 13 to 14.

2) SCR is gated by current from time delay circuit through resistor R1.

3) Capacitor C4 discharges through SCR and the parallel combination of R11 and time channel of the recording head.

4) Current through time channel puts timing mark on tape.

5) Rapid drop in potential at junction of SCR and C4 pulses the digimotor circuitry through C3.

6) Digimotor circuitry acts as below, advancing tape.

7) As C4 discharges, current rhrough SCR drops to low level and SCR shuts off.

8) C4 charges.

9) Timepiece contacts open.

10) After about 45 seconds the output of the time delay circuit jumps about +45 v producing a positive pulse at base of Q1 of the univibrator (Figure D3e).

11) Q1 goes into saturation, biasing the base of Q2.

12) Q2 goes on delivering 15 v to output point 19 and momentarily through C2.

13) Capacitor C2 charges through R3 and R5 keeping Q1 and thus Q2 on.

14) When charging current has decayed sufficiently (after approximately 100 msec) Q1 drops out.

15) Q2 drops out, terminating output pulse.

16) C2 discharges.

17) Timing circuitry and univibrator are now reset.

2. <u>Time Delay Circuit</u> (Figure D3e).

1) Timepiece shorts point 13 to 14.

2) Positive step is coupled through capacitor C1 to base of Q1.

3) Q1 is driven on causing current through R6 and R5.

4) Q2 turns on.

5) Collector of Q2 is coupled to timing circuit, triggering SCR. At the same time, Q3 is turned on with collector going to ground.

6) Q1 and Q3 are kept on by current through R4 and C2 while C2 charges up.

7) When C2 charges up sufficiently Q1 drops out of saturation and Q2 cannot supply enough current to maintain charge on C2.

8) C2 discharges through R4, R3, R8 and R9.

9) When C2 discharges sufficiently Q1 and Q2 drop out.

10) Q3 drops out.

11) Collector of Q3 goes to +45 volts and is coupled to univibrator triggering it.

12) The whole process takes about 45 seconds as opposed to about 30 seconds for the timer; thus false triggering of the digimotor and the univibrator is prevented.

3. Digimotor Circuitry (tape advance)

1) Timing circuit action results in current through R5, D1, and R7 (Figure D3a) biasing the base of TR2.

2) TR2 goes on, biasing TR3. TR3, in turn, biases TR4.

3) TR4 goes on, effectively grounding low side of digimotor.

4) Capacitor C2 maintains bias on TR2, keeping TR3 and TR4 on long enough for C5 to discharge through the digimotor.

5) When the potential of C5 drops sufficiently, Zener diode D2 fires, biasing TR1 into conduction.

6) TR1 maintains +45 volts at its collector, preventing further triggering until the potential of C5 has risen again to nearly +45 volts.

7) Tape advances.

8) When C2 discharges sufficiently, TR2 turns off.

9) TR3, TR4 turn off.

10) C5 charges.

11) TR1 turns off.

12) Digimotor circuitry is now reset.

4. Temperature Sensor Circuit

1) The output of the univibrator (rectangular pulse approximately +15 v and 100 msec long) is fed to the temperature sensor circuit (Figure D3d) from point 19.

2) Zener voltage of D1 is applied to the base of Q1.

3) Q1 turns on, producing regulated output pulse (approximately 6 volts) across Zener D2.

4) Pulse is applied across a resistance bridge including the temperature sensor or equivalent calibration resistor as a leg, the output of which is fed to the recording head.

5. Humidity Sensor Circuit

1) The output of the univibrator is fed to the humidity sensor circuit (Figure D3d) from point 19.

2) Zener voltage of D1 is applied to the base of Q4.

3) Q4 turns on, producing regulated output pulse (approximately 6 volts) across Zener D2.

4) Pulse is applied to the base of Q1 through the humidity sensor or equivalent calibration resistor. Logarithmic characteristic of diodes compensates for non-linearity of sensor producing near-linear relation between voltage at base and humidity.

5) Q1 goes on, biasing Q2 on.

6) Q2 turns Q3 on.

7) Recording head is load for Q3 and thus receives amplified signal.

APPENDIX D

Drawings

Figure D1 - Tape Recorder Assembly

Figure D2 - Circuit Boards

Figure D3 - Schematics

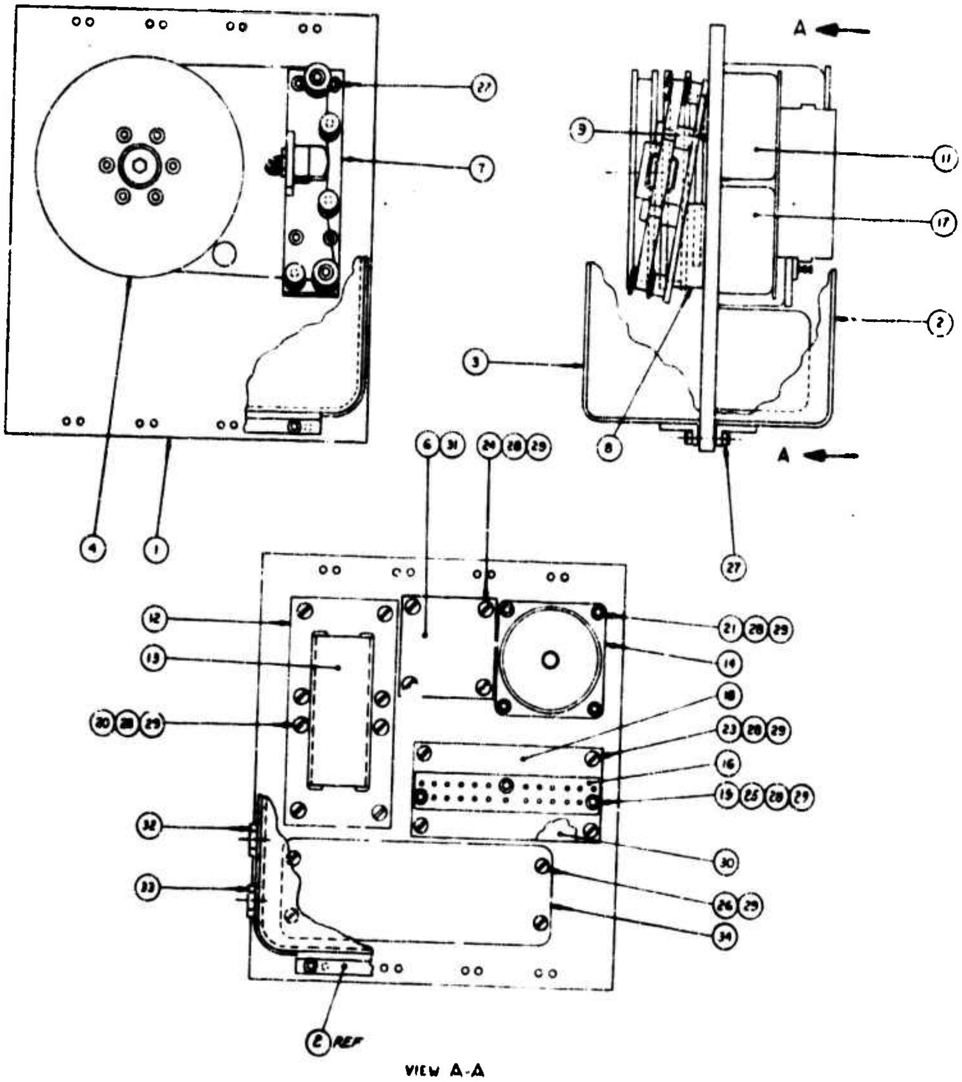


Figure D1. Tape Recorder Assembly.

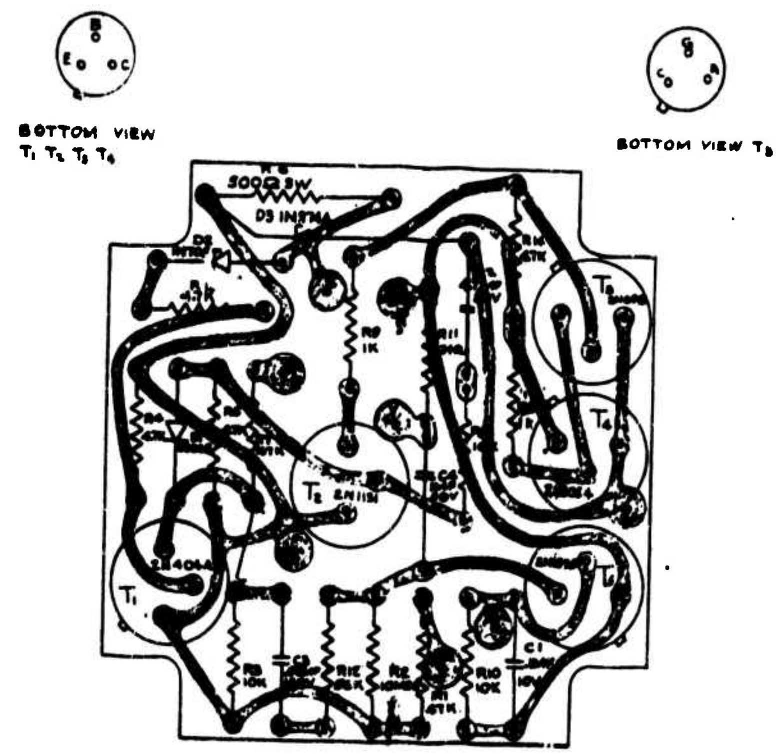


Figure D2a. Motor and Timing Board.

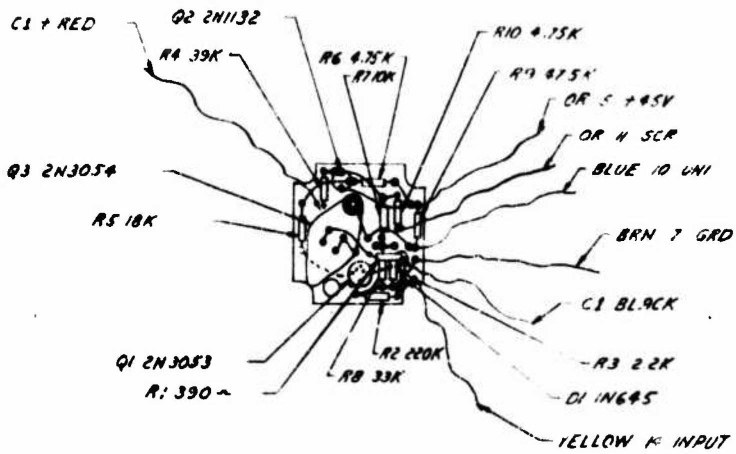


Figure D2b. Time Delay Board.

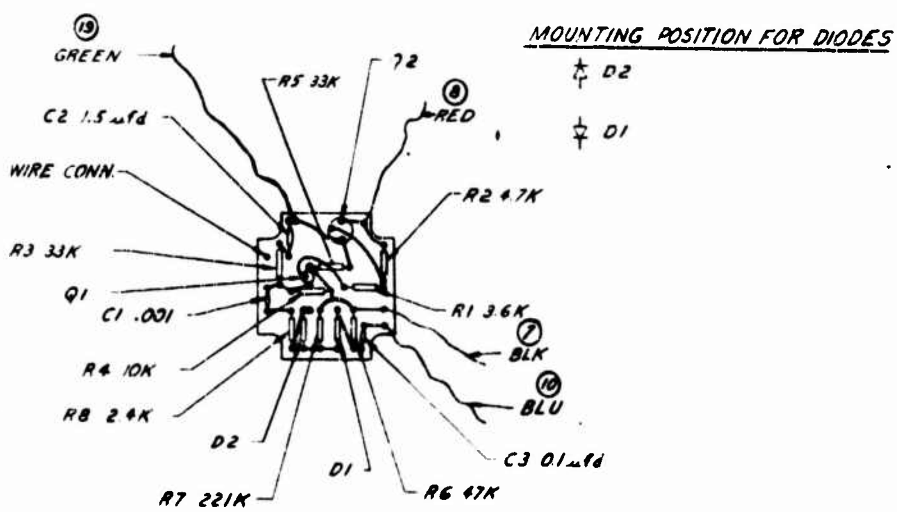


Figure D2c. Univibrator Board.

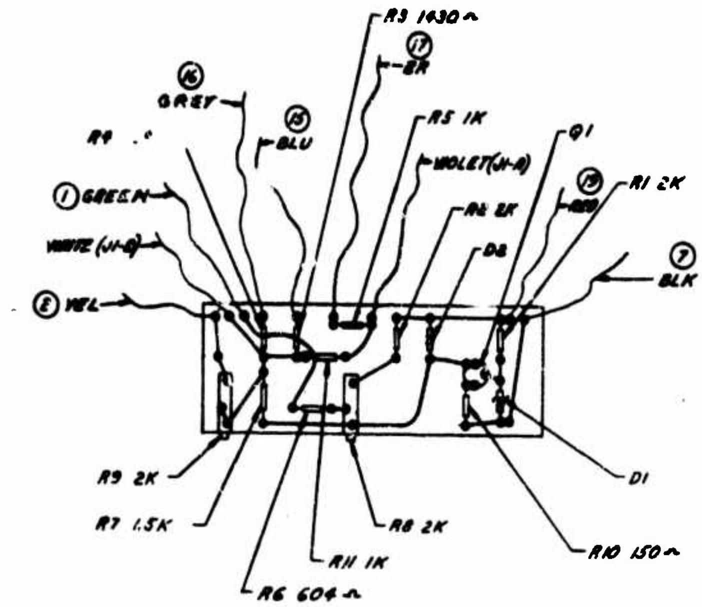


Figure D2d. Temperature Board.

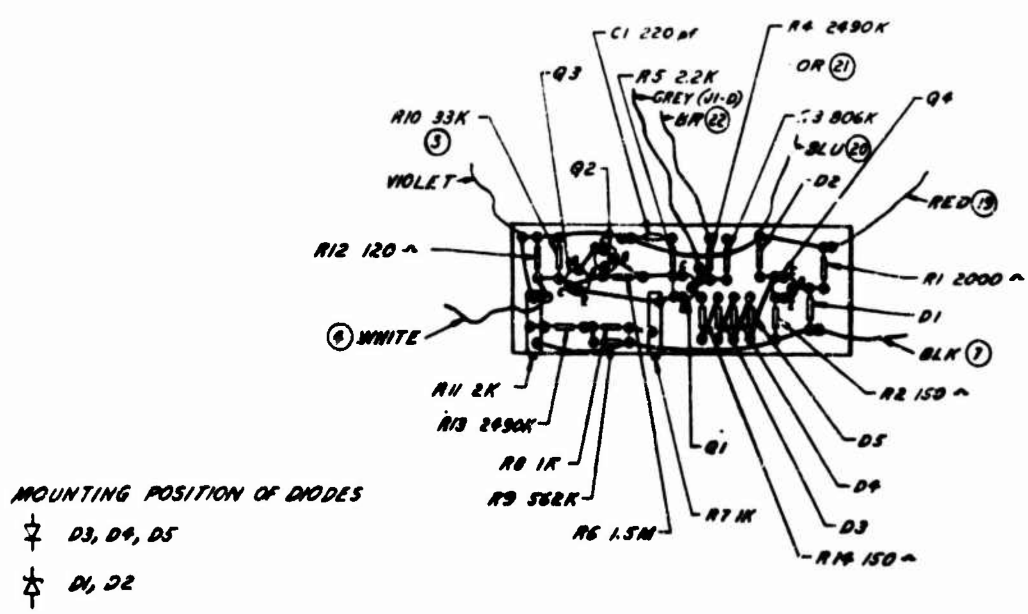


Figure D2e. Humidity Board.

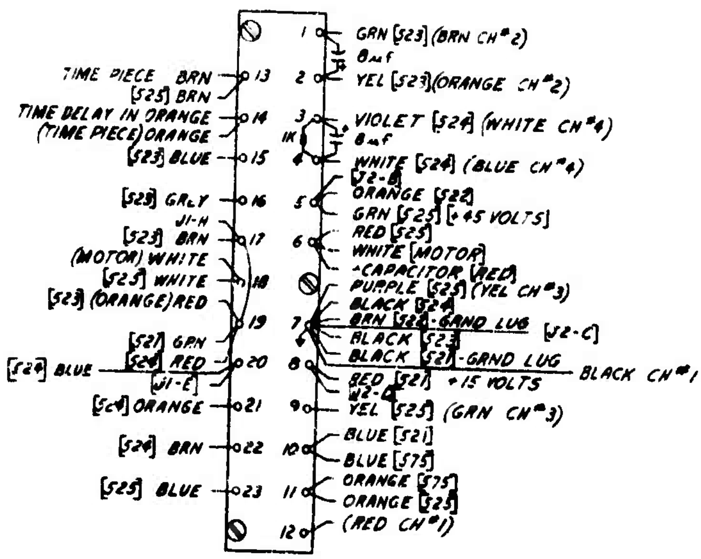
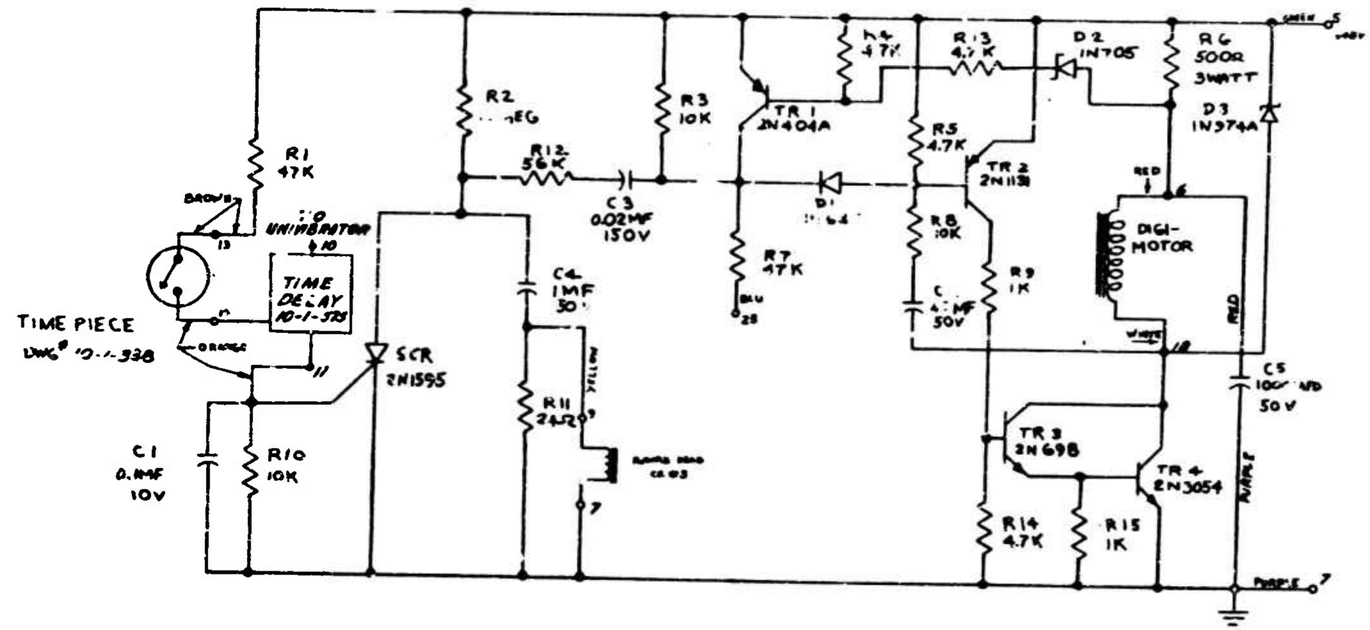
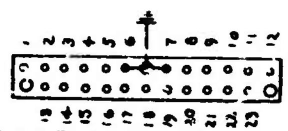


Figure D2f. Terminal Board.

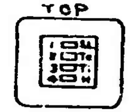


ALL RESISTORS ¼ WATT 10% UNLESS OTHERWISE NOTED

ALL WIRE TO BE #26.

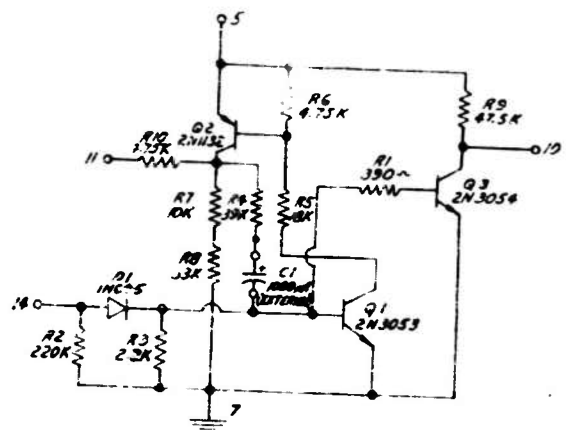


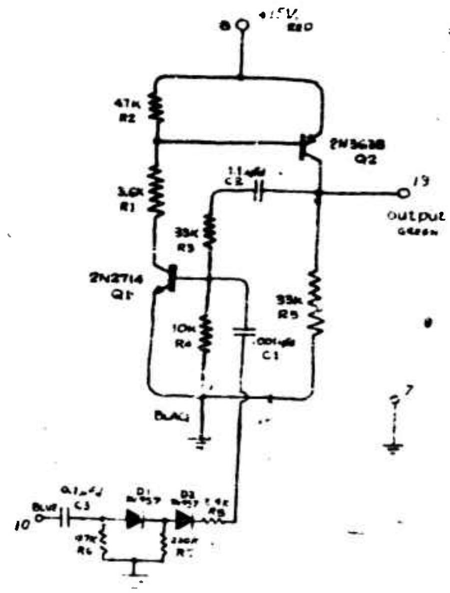
DESIGNATION OF TERMINAL NO.



CHANNEL DESIGNATION

Figure D3a. Timing and Motor Schematic.

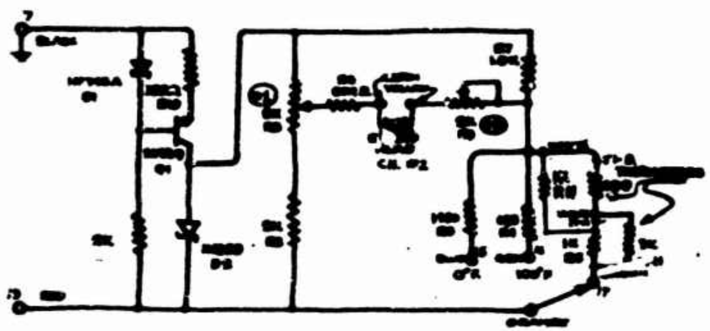


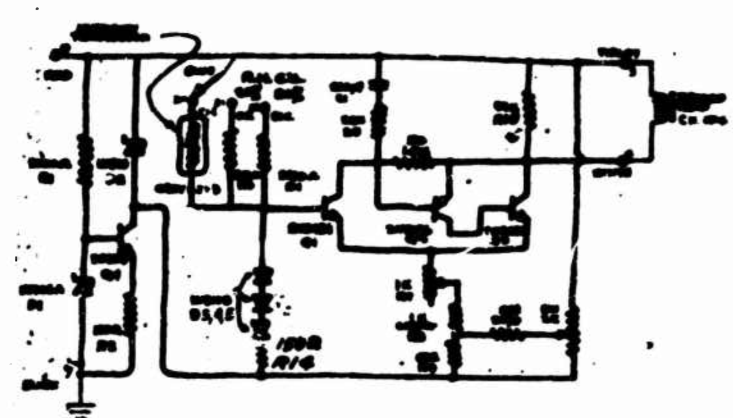


NOTE:
ALL RESISTORS TO BE METAL
FILM 1% 1/8 WATT

Figure D3b. Time Delay Schematic.

Figure D3c. Univibrator Schematic.





NOTES:
1. ALL FIXED RESISTORS TO BE METAL FILM 1% ½ WATT.
2. ALL VARIABLE RESISTORS TO BE WIREWOUND.

Figure D3d. Temperature Schematic.

Figure D3e. Humidity Schematic.

APPENDIX E

Component Function Tables

APPENDIX E

Electronic Circuitry

Individual Component Function

TABLE E I

Digimotor Circuitry (Figure D3a)

Desig.	Description	Function
TR1	Transistor	Prevents digimotor circuitry from triggering at low voltage across C5.
R4, R13	Resistors	Bias elements for TR1.
D2	Zener Diode (4.8 v)	Establishes trip point of TR1.
D1	Diode	Prevents TR1 from removing bias from TR2.
R5, R7	Resistors	Bias elements for TR2.
R8, C2	Resistor, Capacitor	Maintain bias on base of TR2.
R6	Resistor	Current limiter.
TR3, TR4	Transistors	Provide discharge path for C5.
R14, R15	Resistors	Bias elements for TR3, TR4.
C5	Capacitor	Current source for digimotor.
D3	Zener Diode (36 v)	Regulates voltage across digimotor.
TR2	Transistor	Turns TR3, TR4 on and off.
Digimotor	Rotary Stepping Motor	Indexes Tape.

TABLE E II

Timing Circuitry (Figure D3a)

Desig.	Description	Function
R10	Resistor	Establishes, along with time delay output, gate current and gate voltage for SCR.
Timepiece	Electric Watch	Pulses gate once each hour.
C1	Capacitor	Helps prevent noise triggering of SCR.
SCR	Silicon Controlled Rectifier	Provides path of discharge for C4 and triggers digimotor circuitry.
C4	Capacitor	Current source for time channel.
R11	Resistor	Reduces discharge time of C4.
R2	Resistor	Charge path for C4.
R12, R3	Resistors	Voltage divider.
C3	Capacitor	Differentiates voltage step at SCR, pulsing digimotor circuitry. Also d.c. isolates timing circuitry from advance trigger.
R1	Resistor	Limits time delay trigger current.

TABLE E III

Time Delay Circuit (Figure D3b)

Desig.	Description	Function
R1, R2	Resistors	Provide discharge path for C1.
C1	Capacitor	Blocks d.c. and low frequencies.
D1	Diode	Blocks negative pulses.
Q1	Transistor	Initiates time delay and maintains it.
R5, R6	Resistors	Bias elements for Q2.
Q2	Transistor	Provides step to trigger SCR.
R4, C2	Resistor, Capacitor	Time delay elements.
R7, R8	Resistors	Current limiting for Q2.
R10	Resistor	Establishes Q3 base current.
R9	Resistor	Limits current through Q3.
Q3	Transistor	Provides univibrator trigger.
R11	Resistor	Limits trigger current to SCR.

TABLE E IV

Univibretor (Figure D3c)

Desig.	Description	Function
C3	Capacitor	Differentiates signal and blocks d.c.
R6, R7, D1, D2	Resistors, Diodes	Prevents noise triggering.
R8	Resistor	Esteblishes Q1 bese current.
C1	Capacitor	Blocks slowly varying input.
R4	Resistor	Initial Q1 bias element.
Q1	Trensistor	Initiates delay end maintains it.
R1, R2	Resistors	Q2 bias elements.
Q2	Transistor	Provides sensing circuit signal.
R5	Resistor	Loed for Q2.
C2, R3	Capacitor, Resistor	Time delay (pulse width) elements.

TABLE E V

Temperature Sensing Circuit (Figure D3d)

Desig.	Description	Function
R1	Resistor	Limits D1 current.
D1	Zener Diode	Establishes bias on Q1.
Q1	Transistor	Establishes D2 current.
R10	Resistor	Limits current through Q1.
D2	Zener Diode	Provides regulated pulse for bridge.
R2, R7	Resistors	Arms of bridge.
R8	Potentiometer	Output offset adjustment.
R3, R4	Resistors	Calibration resistors.
R5, R11	Resistors	Linearizes sensor characteristic.
R9	Potentiometer	Output gain adjustment.
R6	Resistor	Limits current through head.

TABLE E VI

Humidity Sensing Circuit (Figure D3e)

Desig.	Description	Function
R1	Resistor	Limits current through D1.
D1	Zener Diode	Establishes bias on Q4.
Q4	Transistor	Establishes D2 current.
D2	Zener Diode	Provides amplifier with regulated pulse.
R2	Resistor	Limits current through Q4.
R3, R4	Resistors	Calibration resistors.
R14, D3, D4, D5	Resistor, Diodes	Linearize sensor characteristic.
Q1	Transistor	Amplifier input transistor.
C1, R5	Capacitor, Resistor	Provides initial Q1 turn-on path.
R6	Resistor	Bias element.
Q2	Transistor	Buffer.
Q3	Transistor	Output transistor.
R10	Resistor	Output load.
R7	Potentiometer	Output gain adjustment.
R8, R9	Resistors	Limit current at offset extremes.
R13	Resistor	Limits current through offset tap.
R11	Potentiometer	Output offset adjustment.

APPENDIX F

Reference List of NLABS Drawings

Drawing No.	Dated	Title
02-10-1-296	11-22-65	Tape Reel Mounting Assembly
01-10-1-298	11-29-64	Terminal Board Assembly (Tape Deck)
01-10-1-299	12-06-63	Tape Head Mounting Assembly
00-10-1-300	1-10-64	Potted Electronic Assembly
01-10-1-301	3-03-64	Time Piece Potting Assembly
01-10-1-302	12-16-64	Capacitor Plate & Clamp Assembly
01-10-1-303	2-20-70	Incremental Stepping Motor Assembly
01-10-1-305	3-31-64	Capacitor
02-10-1-307	12-16-64	Mount Support Tape Guide
02-10-1-308	12-23-63	Wedge
02-10-1-311	12-31-63	Center Post
00-10-1-312	11-26-63	Thrust Ball Bearing Assembly
01-10-1-313	11-28-63	Spur Gear
01-10-1-314	11-22-63	Tape Reel
01-10-1-315	11-22-63	Upper Reel Retainer
00-10-1-316	12-31-63	Lower Reel Retainer Assembly
00-10-1-317	1-02-64	Upper Reel Hub Assembly
01-10-1-318	11-28-6[illegible]	(Regulator) Spiral Spring

Drawing No.	Dated	Title
00-10-1-319	3-06-64	Spring Retainer Disc
02-10-1-320	11-26-63	Lower Reel Retainer
00-10-1-321	1-02-63	Bronze Bearing
01-10-1-322	11-26-63	Upper Reel Hub
00-10-1-323	3-06-64	Truarc Ring
01-10-1-327	12-09-63	Tape Head (4-Channel Rear Mount)
01-10-1-328	12-09-63	Head Mounting Bracket
00-10-1-329	12-09-63	Fixed Tape Guide
00-10-1-330	12-10-63	Tape Roller
01-10-1-331	12-10-63	Tape Roller Post
00-10-1-332	12-11-63	Truarc Ring
00-10-1-333	1-10-64	Potting Case
00-10-1-334	1-10-64	Printed Circuit Board Assembly
00-10-1-335	1-10-64	Potting Compound
00-10-1-336	1-08-63	Printed Circuit Board
01-10-1-338	Undated	Time Piece
00-10-1-342	3-31-64	Capacitor Mounting Plate
00-10-1-343	12-16-64	Capacitor Clamp
02-10-1-344	2-20-70	Motor
01-10-1-345	2-20-70	Pinion Shaft
00-10-1-515	2-20-70	Mounting Plate Terminal Board
00-10-1-516	2-20-70	Plate

Drawing No.	Dated	Title
01-10-1-517	May 72	Univibrator & Time Delay Electronic Assembly Potted Unit
00-10-1-518	2-20-70	Temperature & Humidity Electronic Assembly Potted Unit
00-10-1-519	2-20-70	Capacitor Potted Assembly
02-10-1-520	May 72	Wiring Diagram (Temp, Hum, + S.L.)
01-10-1-521	May 72	Schematic Univibrator
02-10-1-523	May 72	Schematic Temperature Sensor
02-10-1-524	May 72	Schematic Humidity Sensor
02-10-1-525	May 72	Schematic, Motor and Time Circuits
00-10-1-526	2-20-70	Covers (Top & Bottom)
00-10-1-527	2-20-70	Base Plate
00-10-1-528	2-20-70	Tape Recorder Assembly (Combination)
10-1-569	Mar 72	Spacer
01-10-1-570	May 72	P.C. Board Assembly Univibrator Tape Recorder
10-1-571	Mar 72	P.C. Board Assembly Temperature Sensor Tape Recorder
01-10-1-572	May 72	P.C. Board Assembly Humidity Sensor Tape Recorder
01-10-1-573	May 72	Terminal Board Wiring Connections Tape Recorder
01-10-1-574	May 72	Time Delay Board
10-1-578	Apr 72	Time Delay Schematic